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NASA Technical Paper 1605

Nitrogen Dioxide Vapor Penetration of Chlorobutyl Rubber SCAPE Suits Under Operational Conditions

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FEBRUARY 1980

NASA

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Nitrogen Dioxide Vapor Penetration of Chlorobutyl Rubber SCAPE Suits Under Operational Conditions

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National Aeronautics
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**Scientific and Technical
Information Office**

1980

ACKNOWLEDGEMENT: The authors gratefully acknowledge the assistance of Coleman J. Bryan of Kennedy Space Center for performing pull test and photographing of exposed specimens, Lloyd G. Bostwick of Kennedy Space Center for SEM investigation of the effects of N_2O_4 exposure to the rubber nomex bond and Peter J. Welch for mathematical computation of the NO_2, CO_2 and helium permeation rate relationship.

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NITROGEN DIOXIDE VAPOR PENETRATION OF CHLOROBUTYL RUBBER SCAPE SUITS UNDER OPERATIONAL CONDITIONS

INTRODUCTION

The Self-Contained Atmospheric Protective Ensemble (SCAPE Suit) is a garment which is worn to protect personnel engaged in the handling of oxidizers and hypergolic propellants. The suit is designed to minimize the risk involved when performing necessary functions in a potentially hazardous environment both by liquid contact and vapor penetration. The suit material is a chlorobutyl rubber coated "Nomex" aramid fabric. Breathing air and cooling is provided by a self-contained liquid air backpack which provides an air flow between 0.8 and 1.3 SCFM depending on the amount of cooling required. The backpack will provide air for approximately two hours but operationally is seldom used over 70 minutes. A positive pressure within the suit is maintained by pressure relief valves, one mounted directly in front of the helmet and one on each of the upper legs. The helmet relief valve controls the inner pressure in normal work functions. It closes at 0.42 + or - 0.02 inches of water and opens at 0.62 + or - 0.02 inches of water. The leg relief valves operate only when the pressure within the suit increases suddenly and reaches 0.74 + or - 0.02 inches of water.

The several hundred SCAPE suits at KSC have been used on a routine basis, some for as long as 12 years, and although a specification acceptance test for the material has been performed, no evidence could be found that any tests had been attempted on an integrated suit. Further, even though a strenuous cleaning and maintenance program exists, there was no assurance that the 8 to 12 year old suits could still protect the wearer. Preliminary math models (1)* indicated that there could indeed be a problem. We were, therefore, asked to develop a test program which could determine the NO2 concentrations that could occur inside the suits if the wearer were exposed to an oxidizer spill.

To develop this program, consideration was given to the fact that SCAPE suits are expensive items and that all of the suits currently in stock will be needed in the Shuttle Program. If large amounts of oxidizer were allowed to come into contact with the suits, they might be damaged so severely that they could not be reused. Therefore, it was decided that an appropriate tracer compound should be selected to model penetration of oxidizer vapors. Further, several types of penetration could take place such as permeation through the suit material and diffusion

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*The number in parentheses indicates Bibliography references.

through the relief valves. In view of these considerations, the following test scheme was devised:

1. Select inert tracer gas or gases.

2. Establish a relationship between the permeation of NO2 and that of an inert tracer gas through unused material.

3. Establish a relationship between the leakage of NO2 and the tracer gas through the suit relief valves.

4. Test unmanned suits in an atmosphere of the tracer compound to determine the penetration due to leakage at the relief valves.

5. Perform unmanned suit chamber test to study the effects of suit modification.

6. Perform a manned suit test in a tracer compound atmosphere to determine the maximum vapor penetration rate and concentration using a typical inventory suit.

7. Perform manned suit test to determine the effect of modification made to the suit to improve its resistance to penetration.

The preceeding series of tests were designed to assess vapor penetration characteristics of the suits, but they could not reveal what the consequences of prolonged contact with oxidizer liquid would be. Also, many of the inventory suits exhibited visual anomalies which could represent potential defects, and many suits contained repair patches. To determine the damage caused by liquid exposure and to investigate the effects of the visual anomalies and repairs, the following tests were performed:

1. Two hour vapor penetration test of material with visual anomalies taken from inventory suits.

2. Two hour vapor penetration test of material taken from repaired areas of inventory suits.

3. Vapor penetration test on new chlorobutyl material with different post curing histories.

4. Liquid N_2O_4 exposure test of new and used material to determine the effect on appearance and strength.

5. Liquid MMH exposure test of new and used material to determine the effect of fuel.

PENETRATION TESTS OF SCAPE SUITS

Selection of Inert Tracer Compounds

Since a prime requirement of the permeation test on the suits was that it be nondestructive, a substitute gas for NO_2 was needed. Requirements for this inert gas were that it be readily obtainable at KSC, non-toxic, similar to NO_2 in physical properties and easily detected in the low ppm range. CO_2 met all these requirements. It was close to the same molecular size and weight as NO_2 and met the other criteria. A mathematical model (1) indicated further that CO_2 and NO_2 should have similar permeation characteristics.

CO_2 was not satisfactory for use in a manned suit test, however, because it was not possible to completely exclude man-produced CO_2 from the interior of the suit. The only other readily available inert gas that allowed easy detection at low concentration, was not highly toxic, and was not found in quantities around man was helium.

Although there are some important differences between the two chosen tracer gases and NO_2, namely molecular size for helium and chemical inertness for carbon dioxide, testing showed that meaningful comparisons and extrapolated conclusions can be made with reasonable certainty.

Comparison of CO_2 and NO_2 Permeation of SCAPE Suit Material

Several stainless steel cells were fabricated with inlet and outlet ports on the top and bottom. The joining surfaces were welded flat 1/4 inch stainless steel providing 8 holes for 3/8 inch bolts. The material being tested was placed between two 1/4 inch Teflon gaskets, fitted between the top and bottom cell and bolted in place.

The cell was mounted in the test apparatus shown in Figure 1. A Lira Model 300 CO_2 Analyzer was used to measure the CO_2 concentration. The sensitivity of the instrument was improved by increasing the gain almost to its maximum and zeroing the recorder using breathing air as the zero gas. A standard of CO_2 in breathing air was run under the same flow conditions as the zero gas.

The unused 1971 vintage SCAPE material was then analyzed by purging the lower cell with CO_2 while maintaining a flow of breathing air through the upper chamber under a partial vacuum. The results are shown in Figure 2 and in the table below.

An Energetics Science Inc. Ecolyzer NO_2 Analyzer was plumbed into the apparatus in place of the Lira. A NO_2 standard was run under the same flow conditions used for the CO_2 standard. The SCAPE material was then analyzed using a N_2O_4 supply to the lower

cell. A very sharp rise in NO2 concentration noted after 122 minutes was attributed to chemical breakthrough.

	Std., ppm/division	Maximum Concentration ppm	Time to Reach Maximum, Min.	Breakthrough Time, Min.
CO2	0.26	8.1	26	---
NO2	0.02	1.2	100	122

Comparison of the maximum concentrations at the end of two hours, 8.1 ppm CO2 and 1.2 ppm NO2, indicate that the final NO2 concentration within the suit due to permeation can be expected to be 6.8 times less than the measured CO2. Additionally, it has been shown that after exposure to 100% N2O4 vapor, permeation is not measurable for the first 32 minutes.

Relief Valve Leakage

The backstreaming of vapors through the SCAPE relief valves was throught to be a major factor in controlling the inner suit concentration. A special cell was fabricated using a solid plate device with a mounting hole for the valve (Figure 3), and a representitive face relief valve was tested four times in the open position and four times in the closed position. Breathing air supplied to the inner chamber at a rate of 0.3 CFM was

sufficient to make the valve operate (open and close in a rhythmic cycle). At 0.2 CFM the valve remained closed for long periods. The pressure in the inner chamber varied from 0.44 to 0.64 inches of water during the valve operation test and remained below 0.4 inches during most of the closed valve condition runs.

Carbon dioxide was emitted into the outer cell after all calibration and zero adjustments of the Lira 300 CO2 Analyzer had been made. The air in the inner chamber was monitored with a sample probe 2 cm from the valve. Tests were run with the valve operating (0.3 CFM breathing air) and with the valve not operating (0.2 CFM breathing air). The same test was then performed using NO2 to purge the outer chamber and the Ecolyzer NO2 Analyzer to measure the permeation. Results were as follows:

	Valve Operating ppm	Valve Not Operating ppm
CO2	1.4	50
NO2	< or = 0.5	10

Two conclusions can be drawn from the relief valve testing:

1. The two hip relief valves, which operate only during high pressure conditions, are more likely to allow penetration than the face shield valve where backstreaming was suspected.

2. The leakage of NO2 through the relief valve in the closed condition is 5 times less than CO2, and in the operating condition about 3 times less.

Unmanned Suit Test Using A CO2 Atmosphere

Two standard operational SCAPE suits, numbers 607 and 627, were selected at random for nondestructive complete ensemble testing. A test chamber was constructed as illustrated in Figure 4 using CO2 as the tracer gas. It was fabricated of stainless steel, measuring 4 feet square by 8 feet high with a 4 foot square air-tight door containing a large plexiglass window on the front. Several port connectors were mounted on the side for gas inlets, sampling, and monitoring equipment. There was a large closable vent in the base and three port connectors on the side for venting the suit's interior gases. A seven foot tall stand pipe was inserted into the floor vent to insure maximum CO2 concentration around the suit. Both breathing air and carbon dioxide were supplied from "K" bottles for the test. The exterior CO2 concentration was monitored at helmet level by an MSA Lira 300 CO2 Detector with a 0 - 100% range. For interior CO2 concentration a 0 - 50 ppm Lira 300 was used with the sampling probe mounted at the communication microphone. Interior suit pressure was measured from the same probe with a 0 - 20 inch inclined water gauge. A series of valves in both interior and exterior sampling lines allowed known CO2 standards to be

channeled to each Lira unit for calibration purposes. A small air pump was used to bring the suit exterior gas to the Lira while the internal pressure of the suit was sufficient to cause the gas to flow through the interior monitoring analyzer at an average rate of 123 cc/min. The relief valves in the suit were altered so they could be vented directly to the outside of the chamber through flexible hoses (closed loop test) or vented into the chamber as they would be in natural use (open dump test).

A. Open Dump Test

Suit number 607 was installed in the test chamber as illustrated in Figure 4 with the relief valves vented inside the chamber. Breathing air flow into the suit was adjusted to 0.85 CFM (24 l/min) so the face plate valve would open and close rhythmatically. Interior pressure was measured at 0.62 and 0.42 inches of water for the respective valve operations.

The first noticeable rise in CO2 level came after 6 minutes when the interior concentration was 40% (Figure 5). A maximum concentration within the suit of 27 ppm was observed after 32 minutes when the exterior concentration at the top of the chamber was 90% CO2. The CO2 level in the top of the chamber continued to rise to 94% at 44 minutes but no increase in the interior concentration was observed.

The test was repeated with suit number 627. Breathing air flow was set at 1.05 CFM (36 l/min) with relief valves operating rhythmatically as before. First indication of CO2 inside the suit was observed at 4 minutes while the maximum of 23 ppm was not reached until 40 minutes had passed (Figure 5).

B. Closed Loop Test

Suit 627 was set up in the closed loop configuration to measure the effect of the valves on the overall leak rate. Air flow was kept at 1.05 CFM so that the face valve would operate normally. An increase in interior CO2 concentration began after 5 minutes and reached a maximum of 9.8 ppm after 30 minutes. Exterior CO2 concentration reached 100% (Figure 5) after 36 minutes of flushing.

C. Verification of Relief Valve Leakage Test

An additional test was initiated to verify the data obtained from the small cell relief valve test which had indicated the most of the valve leakage occurred when the valves were not operating. The face valve on suit 607 was vented to the outside as with a closed loop test while the two hip valves were exposed to the CO2 atmosphere as in an open dump test. In this configuration CO2 level reached 28 ppm. With the hip valves sealed off and only the face plate valve operating in an open dump configuration,

only a 10 ppm level was reached inside the suit. The close agreement of these values with the open dump and closed loop tests (Figure 5) indicate that most of the leakage into the suits was occurring at the hip relief valves which are in a closed position during normal suit operation.

D. Effects of CO2 Exterior Concentration

Tests were also performed in the chamber on suit 607 to simulate exterior concentrations that might be found during actual operations. In an environment of 0.2% CO2 no leakage was observed in 2 hours (Figure 6). At 1.2% a 3.6 ppm level was reached and maintained after 60 minutes. With a concentration of 5% a level of 17 ppm was obtained after 50 minutes. With a 55% exterior CO2 level and higher, a maximum value of 27 ppm was reached in about 30 minutes. From Figure 6 the maximum interior concentration in the predicted 26% environment of a spill situation is projected to be 21 ppm CO2.

E. Unmanned Chamber Test to Determine the Effects of Suit Modifications

Calibration of the MSA 202 High Sensitivity Lira CO2 Detector was performed before and after each suit analysis. Reproducibility and stability were excellent. Sensitivity was determined by flowing a standard 10 ppm mixture of CO2 in breathing air through

the detector at the same rate exhibited by the flow rate of breathing air into the suit of 33.4 /min. The measured sensitivity in the detector high range detection mode was 0.25 ppm/div and in the low detection range 0.061 ppm/div as recorded on an HP 10 mv recorder. The exterior concentration was monitered with a Lira 300, 0 - 100% CO2 detector and calibrated at 100% by flowing gas from the CO2 K bottle supply.

Carbon dioxide suit penetration tests were run in the large test chamber. Breathing air flow was established at 33.4 /min into the suit chest penetration port. Once a zero base line was obtained, CO2 was dumped into the bottom of the chamber with the exit "K" bottle pressure set at 15 psig. The pressure within the chamber was monitered and adjustments made to the CO2 pressure regulator if the tank pressure exceeded 0.04 inches of water. The suit interior concentration was monitered with the sampling probe in the vicinity of the helmet communication microphone. Before each analysis the sampling line was attached to a 0 - 20 inches of water inclined pressure gauge and the suit interior pressure monitered at several flow rates.

Tests were conducted in the following order:

1. Suit No. 624 with no relief valve flaps.

2. Suit No. 624 with a 2 1/2" face relief valve flap and 3 1/2" hip relief valve flaps.

3. Suit No. 624 with a 1 1/2" face relief valve flap and 3 1/2" hip relief valve flaps.

4. Suit No. 624 with all relief valve flaps cut to 1 1/2".

Breathing Air Flow (l/min)	Interior Suit Pressure (Inches of Water)			
	Test 1	Test 2	Test 3	Test 4
15	0.31 - 0.41	0.50	0.45	0.45
20	0.32	0.55	0.50	0.50
30	0.36	0.65	0.60	0.60
33.4	0.38	0.69	0.64	0.64

Pressure test results given above indicate the pressure within the suit is nearly doubled by the addition of the relief valve flaps and therefore the CO2 penetration should be less. Cutting one inch from the face valve results in a 10% loss in pressure but cutting the hip relief valve flaps to the same length as the face relief valve (1 1/2") does not affect the interior pressure.

Carbon dioxide penetration of SCAPE Suit No. 624 is plotted in Figure 7 at each of the configurations. Penetrations of configurations #3 and #4 were so close that they were plotted on the same line.

Comparing the maximum interior concentration observed in 2 hours reconfirms results obtained in Helium Penetration Test. Adding the flaps to the suit relief valves with the face flap being 2 1/2" long and hip flaps 3 1/2" long lowers the concentration by about 20%. Additional cutting of 1 inch from the face relief valve making it 1 1/2" long increases the concentration by 7% while cutting the hip flaps to the same length, 1 1/2", has no effect.

Test Conclusions

Carbon dioxide penetration test have confirmed that the addition of relief valve flaps to protect against impingement leakage has improved the ability of our present SCAPE suit to resist vapor penetration. Cutting the face relief valve flap to 1 1/2" for better operational characteristics has not compromised this improvement by much (7%) and cutting the hip relief valve flaps, to further improve it's operational characteristics, to 1 1/2 inches will result in little or no decrease in resistance to vapor penetration.

Unmanned and Manned Suit Test Using a Helium Atmosphere

A Helium Leak Detector, CEC Model 24-120A was used to measure the interior suit concentration. Calibration was achieved by flowing a series of known quantities of helium and breathing air into the suit and calibrating the detector in ppm/dividion. Once calibrated, a record was kept of instrument sensitivity by reproducing the value obtained from a 7.2 x 10-7 atm cc/sec standard leak.

The exterior concentration was measured by obtaining timed grab samples from the three side ports of the chamber (Figure 8). The helium supply was regulated so no increase in pressure was noted in the chamber. Analysis of the grab samples, performed on a 21-104 CEC Mass Spectrometer, showed that helium within the chamber reached 90% after 22.5 minutes.

A. Unmanned Suit Tests

The initial test performed was a comparison of closed loop (relief valve exhaust vented out of the chamber) to open dump (relief valve exhaust emptying into the chamber) using "K" bottle, regulated, breathing air as the purge supply. The observed difference again indicated a major portion of the leakage was occurring at the non-operating relief valves (Figure 9). Ratioing the maximum concentration of CO2 found in the

previous test to the helium found in this test of the same suit indicated that CO2 leakage was 28 times less than helium.

$$\text{Suit 627 Closed Loop } \frac{\text{Helium}}{\text{CO2}} = \frac{265 \text{ ppm}}{9.8 \text{ ppm}} = 27$$

$$\text{Suit 627 Open Dump } \frac{\text{Helium}}{\text{CO2}} = \frac{670 \text{ ppm}}{24 \text{ ppm}} = 28$$

Additional chamber testing was performed with suit no. 607 using the prescribed air flow of 1.3 CFM supplied by the breathing air "K" bottles. The helium concentration at the communication microphone mounted inside the helmet rose to 586 ppm in about 45 minutes (Figure 10). The maximum concentration, although somewhat lower than the open dump of suit 627 (670 ppm), was felt to be a reasonable result.

The "K" bottle breathing air supply was then removed, and a charged liquid air backpack mounted within the suit. While using this new air source, the suit pressure, which was monitered continuously at the front entrance port with an inclined water manometer, varied throughout the test between 0.44 and 0.62 inches of water. The maximum concentration of helium observed at the communication microphone within the suit was 741 ppm (Figure 10). The difference in maximum concentration between the backpack air supply and the "K" bottle air supply is attributed to the fact that the "K" bottle supply was set at the prescribed flow of 1.3 CFM regardless of suit pressure or relief valve

action. The flow rate produced by the liquid air backpack was not known exactly, but a range of 1.0 to 1.2 CFM was suggested.

B. Manned Suit Tests

A man fitted with a liquid air backpack donned suit no. 607 and entered the chamber for testing. The suit pressure was monitered throughout the normal run. The closing point of the relief valve was lower in this test, 0.32 instead of 0.44 inches of water, while its venting point was the same 0.62 inches of water. Whether this difference was due to the breathing action of the man or change in interior volume was not determined. The helium concentration within the suit rose at a rate close to that observed in the unmanned test (Figure 10). The maximum concentration of helium observed was 740 ppm.

A series of exercise tests were performed before concluding the manned test to determine possible momentary increases in concentration due to certain types of movement. Table 1 lists the type of movement, pressure change, and helium concentration change within the suit. The equilbrium concentration was re-established within 4 minutes in all cases where an increase was observed.

With these tests, a relationship between helium and carbon dioxide leak rate in actual manned situations has been

established. A plot of carbon dioxide versus time during manned operations can be derived by dividing the helium values by 28. Further predictions can be made of CO2 levels one might experience on a momentary basis when performing certain motions by referring to helium values in Table 1.

C. Manned Suit Test to Determine the Effect of Suit Modification to Improve its Resistance to Penetration

A series of chamber tests were run to determine if modifing a suit to resist liquid impingement had any effect on its capability to resist gas penetration. Modifications of Suit No. 627* included boot and glove unsupported butyl covers, faceplate sealed and flapper valves over each of the three suit relief valves. Initial unmanned testing with both "K" bottle air supply and unmanned backpack supply was performed with the length of the face relief flapper valve as received, 3 7/8 inches. The manned run and final unmanned "K" bottle air supply run was made with 1 3/8 inches cut from the bottom of the flapper leaving a length of 2 1/2 inches.

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*Suit used in earlier testing without modification.

Calibration was performed before and after each suit analysis. The sampling line and the air supply line unit was removed from the suit and attached to a 10 liter exterior mixing chamber. Breathing air was passed into the chamber at 30 l/min and helium added to the air at any selected rate between 3 and 100 cc/min. The ppm value was assigned based on the flow rate of the two gases. A helium leak detector, CEC Model 24-120A was used for all analysis.

Suit helium penetration tests were performed in the large test chamber. Since tests have shown that the exterior concentration of helium under the flow and pressure conditions used would be greater than 90% after 15 minutes, no analysis was performed on the suit exterior gas.

The interior concentration was measured with a sampling probe placed in the vicinity of the helmet communication microphone. Interior suit pressure was recorded via the air supply line whenever the liquid air backpack was in use. Backpack flows were measured by the supplier before they delivered the units.

Tests were conducted in the following order:

1. Unmanned, "K" bottle breathing air supply at 30 l/min. Suit 627, modified with 3 7/8 inch face relief valve flapper.

2. Unmanned, backpack air supply at 33.42 l/min., suit 627 modified with 3 7/8 inch face relief valve flapper.

3. Manned, backpack air supply at 33.42 l/min., suit 627 modified with 2 1/2 inch face relief flapper.

4. Unmanned, "K" bottle air supply at 33.42 l/min., suit 627 modified with 2 1/2 inch face relief flapper.

For tests one and two, helium concentration within the suit reached a maximum of 332 ppm after 56 minutes when using the backpack as the air supply. The "K" bottle air supply was 3.4 l/min slower than the backpack but it reaches a maximum at the same time as the back supply with a slightly higher concentration. Both tests were conducted on the modified suit as recieved, this data is plotted in Figure 11.

For tests three and four, the helium concentration found within the suit during the manned experiment and in an unmanned run under the same conditions is shown in Figure 12. The face relief flap was cut to 2 1/2 inches for the manned test thereby necessitating the additional unmanned test of the same length flapper.

During the manned test a series of movement experiments were carried out once the helium concentration appeared to have reached equilibrium. The solid line in Figure 12 is the actual recorded data with only minor averaging out of noise. Peaks and valleys observed are due to specific movements within the suit which are shown in Table 2. The dashed line, which represents the unmanned tests, defines the average of the peaks and valleys of the manned run. The maximum concentration of 456 ppm was observed after 45 minutes.

Test Conclusions

The first helium penetration test performed on Suit 627 (5-4-78) was done with an air flow rate into the suit of 1.05 CFM. Figure 13 is a comparison of that data, corrected for flow to data for the newly modified suit run at the same flow rate of air as the backpack used for the manned experiment, 1.18 CFM. The test was run first with the full face relief valve flap, 3 7/8 inches. The length of the flap was then reduced to 2 1/2 inches and a manned run was made followed by an unmanned run. The plot observed using "K" bottle air at the same flow rate on the modified suit with the 2 1/2 inches long, matched the manned run so closely that we can consider it as the average plot of the manned run. The data clearly indicates that we have improved the capability of the suit to resist penetration.

The 3 7/8 inch flap on a modified suit reduced the maximum helium concentration by 260 ppm. At 100% exterior concentration this would reduce the NO2 observed after equilibrium by 1.9 ppm.

The 2 1/2 inch flap on a modified suit reduced the maximum helium concentration by 120 ppm thus reducing the NO2 by 0.9 ppm. Since this is the currently accepted modified suit configuration, a separate plot of the data is given in Figure 14.

Manned test to examine the effects of movement on the interior pressure and helium concentration in the modified suit is plotted in Figure 15. The normal pressure in the standing position was 0.7 inches of water. The unmodified suit pressure varied from 0.42 to 0.62 at a fairly constant rate except when extreme movements were made.

It can be seen in Figure 15 that a deterimental effect was exhibited above the average three times. Each of these instances occurred when going from a standing to a squatting position. The test conducted 5-4-78 before the modification also showed this change, but it appeared when going from the squatting to the standing position. We can only speculate at the present that the addition of the flaps on the hip relief valves altered or reversed some function of the suit mechanics.

Similar movement experienced going to the kneeling position appeared to reduce the helium concentration with the suit.

Regardless of the mechanism involved the largest increase occurred on the first squat. The change in concentration was 280 ppm. In a 100% NO2 atmosphere this quantity would equate to 2.0 ppm NO2. The largest deviation recorded when going from the squatting to the standing position during the 5-4-78 manned test of an unmodified suit was 1.6 ppm NO2. It should also be noted that the 2.0 ppm decreased to 1.6 ppm in 48 seconds.

EFFECTS OF LIQUID EXPOSURE, WEAR, AND REPAIR METHODS

Cell Test of Used Material

Portions of inventory suits which exhibited visual anomalies were removed and subjected to 100% N2O4 vapor exposure for 2 hours under simulated conditions of 283 l/min air flow on the inside of the material at 0.4 to 0.6 inches of water pressure as shown in Figure 16. Exposed Nomex and tunneling with pronounced creasing appear to be the sites in the material where attack is most damaging. Table 3 lists the description and results of the testing. Figures 17, 18 and 19 are photographs of some of the defects.

Test of Repair Methods

A 1/2 inch square of outer butyl coating was removed from the center of 8 samples of new unused 1971 vintage material. Two were used as controls, two were repaired with 3 coats of adhesive, two were repaired by using the adhesive with non-supported butyl rubber patch and two by adhesive and supported patch.

The two unrepaired samples allowed NO_2 to penetrate after 41 minutes and 31 minutes respectively with the upper chamber reaching a concentration of 2.7 ppm and 3.6 ppm respectively after 2 hours exposure. The top of the cell was maintained at a pressure of Ø.42 inches water and a flow of 1 SCFH throughout the test (Figure 12). None of the repaired samples showed any indication of NO_2 penetration within a 2 hours period.

Effects of Cure Time

Samples of Fairprene YXØØ1, a material with the same formulation as the present material except for the flame retardant, were subjected to N_2O_4 liquid and vapor to determine the effectiveness of different post curing times on the material resistance to permeation. Three samples were selected: one with no post cure

time, one with the normal post cure time of 1 to 1.5 hours at 300 degrees - 320 degrees F, and one with a curing time twice as long as the standard product at the same temperature.

A. Liquid Exposure

Six 2 inch diameter circular disks were cut from each of the samples. Disks from each sample were exposed to liquid N2O4 in a millipore funnel for 4, 6, 8, 10, 12 and 14 minutes. After the N2O4 was poured off, the disks were allowed to air dry for 5 minutes before being rinsed with water.

The results of this test can best be described by a comparison of the visual appearance of the non-exposed surface of the three different post cured materials after the various exposure times:

Exposure Time (Min)	No Post Cure	1 - 1.5 Hr. Post Cure*	2 - 3 Hr. Post Cure
4	No Visible	No Visible	No Visible
6	Slight Lightening and Grainy	No Visible	No Visible
8	Light Grainy	Slight Lightening and Grainy	No Visible
10	White Heavy Grain	Light Grainy	Very Slight Lightening and Grainy
12	White Lumpy	White Heavy Grain	Slight Lightening and Grainy
14	White Lumpy	White Heavy Grain	Light and Grainy

*"Normal" Commercial Supplied Fabric.

Thus it can be seen that visible effects appear on the non-exposed side of the no post cured material after 6 minutes exposure, while the normal product has visible effects after 8 minutes and the double post cured product shows visible effects

after 10 minutes. We can therefore conclude that increasing the post cure time increases the capability of the materials to resist the attack of liquid N2O4.

B. Vapor Exposure

The vapor exposure evaluations were performed on duplicate 12.56 sq. in. specimens of the three Fairprene YX001 samples in the stainless steel vapor permeation test cell. The upper portion of the cell representing the inside of the SCAPE suit, was maintained at 0.4 to 0.5 inches of water pressure while flowing 1 SCFH of breathing air through the cell and into the (Model 7630 Analyzer) NO2 Ecolyzer.

The lower portion of the cell was evacuated to 5 inches Hg, and the N2O4 source was open. Purging while pumping was continued for 5 minutes. The system was then allowed to flow freely by removing the pump and partially closing the N2O4 exit valve for an additional 5 minutes. The N2O4 source and then the exit valve were secured to assure that one atmosphere of NO2 was in the lower cell.

All samples were maintained under these conditions until an indication of NO2 was observed in the air flow effluent of the upper cell. This point will be referred to as the breakthrough time.

Material	Breakthrough Sample #1	Sample #2
No Post Cure	3 Hours 23 Min.	3 Hours 5 Min.
Normal Post Cure	3 Hours 27 Min.	4 Hours 8 Min.
Double Post Cure	10 Hours 50 Min.	11 Hours 8 Min.

These results indicated that the standard post cure treatment does very little to increase the material capability to resist NO2 penetration while the double post cured material increases this capability almost 4-fold.

Liquid N2O4 Exposure Tests

A. Permeation

If a N2O4 spill occurs, the suit is likely to receive some exposure to liquid as well as vapor. Five different materials were exposed to a series of timed liquid exposures to determine the visible effect. Each sample of material was cut into eight 2.5 inch diameter circles. The circles were clampled between two halves of a 2.5 inch Millipore filter and N2O4 was poured on top

of the fabric to a depth of 1/4 inch. Exposure times were 0, 2, 4, 6, 8, 10, 12 and 14 minutes. The sample, test conditions and results used were as follows:

Sample A: Unused 1971 material was exposed to liquid N2O4 for the stated time periods. No covering was put over the funnel's top so the N2O4 was at atmospheric pressure. The N2O4 was poured off of the samples after the specified time. The residual N2O4 was allowed to air evaporate for 5 minutes before the fabric was washed with water for one minute.

For the first six minutes of exposure no effects were observed on the unexposed side (inside) of the material. From eight minutes on, the fabric became lighter and the crosswork pattern of the Nomex weave became visible. After two minutes the side exposed to N2O4 became coarse and grainy with much discoloration. As the exposed time lengthened, the grainy appearance melted into a smoother softer looking surface.

Sample B: 1971 Vintage material under similar conditions as "A" except the water wash came immediately after the N2O4 was removed. The visible effects on the nonexposed side were the same as with "A", but there was a distinct coarseness and after 8 minutes bubbles appeared on the surface as the fabric was being washed. With longer exposure time more and larger bubbles appeared.

Sample C: Materials from the upper right arm of an operational 1966 vintage suit was removed and exposed to the liquid at atmospheric pressure. The sample were allowed to air dry for 5 minutes before washing.

The exterior side that was exposed had the same appearance as sample A and B. At six minutes 3 small areas appeared lighter than the rest of the surface indicating possible flaws in the material. These areas continued to lighten over the next 4 minutes and then color stabilized. A more grainy appearance than the 1971 material was observed on the longer exposure samples.

Sample D: Upper arm material from a 1971 suit was used for this test. The conditions were the same as sample "C".

This fabric was much whiter than all the rest and no color changes were noted on the nonexposed side. The exposed side showed the similar effects as the other samples, but seemed to hold up better under test conditions.

Sample BB: Unused 1971 material was exposed as in sample "B" except a cover was placed over the filter top causing a slight pressure on the material. All appearances were similar to the "B" sample but were observed at earlier times.

Summary: The single outstanding difference between samples A and B (unused 1971 vintage material) was the appearance of bubbles on the surface of B. With immediate water wash, bubbles formed from 8 minutes exposure and up. Allowing the N_2O_4 to evaporate (sample A) prior to washing produced no bubble formation through 14 minutes exposure.

When the BB series (covered N_2O_4) was compared to series B (uncovered N_2O_4), the nonexposed side of the uncovered samples after 8 minutes exposure had the same appearance as the covered 6 minute sample indicating that slight pressure on the N_2O_4 liquid causes more rapid penetration of the fabric.

The 1971 suit's upper arm material (D) seemed to hold up much better than the 1966 suit upper arm material (C). Effects noticed in the 1971 vintage material were observed about 6 to 8 minutes earlier on the 1966 vintage samples. The 1971 samples were much whiter than the others, thereby making color comparisons of the nonexposed side difficult.

B. Effect on Strength

The effect of liquid N_2O_4 on the strength of SCAPE suit material was determined using the identical samples discussed in the preceding section and ploting breaking strength against time of exposure (Figure 20). An Instron Model TT-C universal testing

machine was used to determine the tensile strength of the material. Tests were run at ambient temperature at a crosshead speed of 12 inches per minute. Test specimens were cut with die "C" of ASTM D-412. Because of the nature of the sample, no attempt was made to control the direction of the fiber weave.

It can be readily seen that after just 2 minutes of liquid N2O4 exposure, where only a little visible damage has occurred, there is about 73% loss of strength. It seems apparent the Nomex layer is attacked very rapidly by even short exposure to liquid N2O4.

Liquid Monomethyl Hydrazine (MMH) Exposure Tests

A. Permeation

While there had been much work done on oxidizer permeation, there is little information available for fuel permeation, and there are no known established procedures for its measurement. A primary reason is that past experiences have indicated a high unreliability both in preparing and in transferring the sample from its origin to the analytical equipment, especially at the low concentration expected in material permeation.

It was felt that perhaps a spot test that measures the presence of the fuel in close proximity to the inner material would eliminate the sample transfer problems if the test could be

calibrated on a mass basis. These requirements were met by a modification of the MDA Scientific Inc. Continuous Hydrazine Monitor.

The MDA Hydrazine Detection System is based on the chemical reaction of hydrazine with a specially impregnated paper tape. The sensitivity for MMH when using this tape is 25% less than hydrazine but still quite sensitive, the range being 0 to 0.75 ppm with a lower detectable limit being 0.01 ppm and accuracy plus or minus 10% of the meter reading. Calibration of the instrument is accomplished by measuring the intensity of a manufacturer provided stained calibration card. In the modified procedure the paper tape was removed from the instrument and placed near the material.

Two tests were designed utilizing the MDA Hydrazine Monitor, Model 7080, to determine if the material used in the construction of KSC SCAPE ensembles protects the wearer from being exposed to toxic levels of MMH. The present OSHA limit for MMH is 0.2 ppm time weighted average.

The first test consisted of cutting a 2 1/4 inch diameter disk from an unused piece of 1966 material and placing it in a #4 Millipore glass filter holder. The exposed surface of 1.77 sq. inches was covered with about 1/4 inch of MMH. The MDA hydrazine detection tape was inserted through the funnel portion of the

filter holder below the material which placed the tape in direct contact with the frit on which the material rested. After 8 hours exposure the MMH was removed and the surface neutralized with dilute sulfuric acid and then water rinsed. The hydrazine analysis tape was removed and the contact surface divided into three sections. The pieces were mounted on a card similar to the calibration card provided by the manufacturer.

Although no color change was visible on the tape, the instrument indicated that the tape had been exposed to MMH sufficient to yield a reading of Ø.Ø4 ppm for all three sections.

A second sample was prepared by cutting a 6 inch square piece of material from the current DuPont standard product (Std. Product). The sample was placed in the stainless steel cell used in testing oxidizer permeation which exposes 12.56 sq. inches of material to testing. The hydrazine tape was attached to the underside of the material by small pieces of scotch tape, sealed within the cell and the material covered with 3Ø ml of MMH. Four hours later the MMH was neutralized, flushed with water and the cell disassembled. The hydrazine tape was removed and cut into seven sections. Each section was mounted on a card as before.

Section 1, closest to the edge of the cell on one side, gave no indication of the presence of MMH. The remaining sections,

representing transverse sections across the diameter of the cell, all indicated an exposure sufficient to give a reading of 0.01 ppm.

There was some doubt if the stain was fully developed because of the static conditions of the previous test. To test this, a second test was performed where a paper holder was fabricated that would fit within the lower portion of the test cell with its exit plumbed directly to the MDA sample inlet. The MDA operates on a principle of gas passing through the tape at a rate of 234 cc/min. Breathing air was supplied to the lower chamber at a rate sufficient to maintain 0 to 0.2 inch water pressure in the chamber. The test paper was approximately 0.5 inches in diameter (0.2 sq. in. surface area) and within 0.5 inches of the center of the test material. A volume of 30 ml of MMH was placed in the upper chamber.

A sample of the new standard product and unused material purchased in 1971 were exposed to the MMH under the above conditions for four hours. In both cases the tape, removed from the cell, mounted on the analysis card, and the color intensity measured on the MDA, showed no detectable MMH (<0.01 ppm). To assure the validity of the method, MMH samples of approximately known concentrations were prepared. Instrument readings were obtained in the proper ranges.

B. Effect on Strength

Although there was no apparent permeation of MMH, the effect of exposure on material integrity was unknown. Tensile strengths of material exposed to MMH for four hours and of unexposed material were obtained. There was no observed decrease in the strength of the exposed material. In fact, there was an increase which might be attributed to cross-linking of butyl rubber by the amine.

A close visual inspection was made of all samples discs which were exposed to liquid MMH in these tests. None exhibited a visual change on the inner surface, including the eight hour, two inch disc. The exposed surface discolored slightly but no voids, bubbles or cracks were observed.

CONCLUSIONS

NO_2 Exposure

The following factors were considered in attempting to predict the possible NO_2 exposure that a wearer of an operational KSC SCAPE suit would experience if a spill occurred.

1. The high degree of correlation between suits, between closed and open dump analysis using two different tracer gases and

between suit closed loop permeation and cell permeation tests gives confidence that the data obtained by tracer gas modeling is a valid test procedure.

2. Whenever a test parameter was questionable the condition which would tend to give a high concentration was used. A good example of this was the CO2 and NO2 small cell permeation test. Instead of keeping a 0.4 inches water positive pressure on the inside of the material, a partial vacuum was established, thus somewhat accelerating the permeation process. Tests conducted at a later time on material with visual anomalies removed from operational suits were conducted using the 0.4 inches water pressure in the top chamber. Breakthrough and leak rates found closely matched the original cell test performed using a partial vacuum whereas the same material used in the original cell test, when operated at an inside pressure of 0.4 inches water did not breakthrough for over 3 hours.

3. The flow rate used in the permeation cell testing was approximately 1/120th of that delivered by the liquid air backpack used in a full size suit, and since the surface area of the suit was approximately 120 times that of exposed surfaces of the small test cell, we could postulate that leak values obtained in small samples tests would be comparable to the whole suit values. Examination of the actual test dat[illegible]ws that when immediately exposed to 100% CO2, the concentration change across

SCAPE material in the cell starts after 5 minutes and increases to an equilibrium concentration of 8.1 ppm in 21 minutes. The closed loop suit test on suit no. 627 begins its increase after 5 minutes and increases by 9.8 ppm in 25 minutes.

4. Individual relief valve testing showed that backstreaming or countercurrent diffusion was not a problem with the present relief valve design. The problem lies with the two hip relief valves' inability to make a positive seal when under a 0.42 to 0.62 inches of water pressure condition. It also showed that under the same conditions the NO2 leakage would be 1/5th of the measured CO2 concentration within the suit.

The predicted NO2 inner suit concentration graph (Figure 21) at 100% exterior N2O4 was obtained by dividing the difference between the open dump 100% CO2 suit test and the closed loop 100% CO2 suit test (that portion of leakage due to the relief valves) by 5, the reduction factor for converting CO2 to NO2. These values were then added to the NO2 permeation values obtained in the 12.56 sq. in. material cell test (Figure 2). It should be noted that momentary variations caused by certain activities, shown in Tables 1 and 2 and Figure 15, can result in an increase of interior concentration of as much as 1.6 ppm NO2 caused by a quick deep knee bend then standing up. The duration of this exposure would be 3 minutes.

The predictive curve shows that if a man suited in a normal KSC Inventory SCAPE suit is suddenly exposed to 100% N_2O_4 vapor he will not experience an increase NO_2 within the suit for 12 minutes. A gradual increase within the suit will then begin, reaching 3.4 ppm in an additional 28 minutes (total time 40 minutes). Any action from this point on which would cause a momentary vacuum within the suit could raise the level within the suit to 5 ppm, the OSHA TLV. Without any movements of this type, the level within the suit would remain below the TLV for the entire 2 hours.

The atmospheric concentration of NO_2 produced by a large spill was predicted by KSC Fluids Systems Division to be 26% (2). A predictive curve can be drawn for the exterior value of 26% NO_2 (Figure 22) if the "worst case" situations of 100% N_2O_4 small cell permeation test and 100% CO_2 closed loop suit test are used as test parameters.

The constructed graph (Figure 22) indicates a period of 17 minutes before any NO_2 increase would be experienced within the suit and that the level would remain below 3.5 ppm for the entire 2 hours.

MMH Exposure

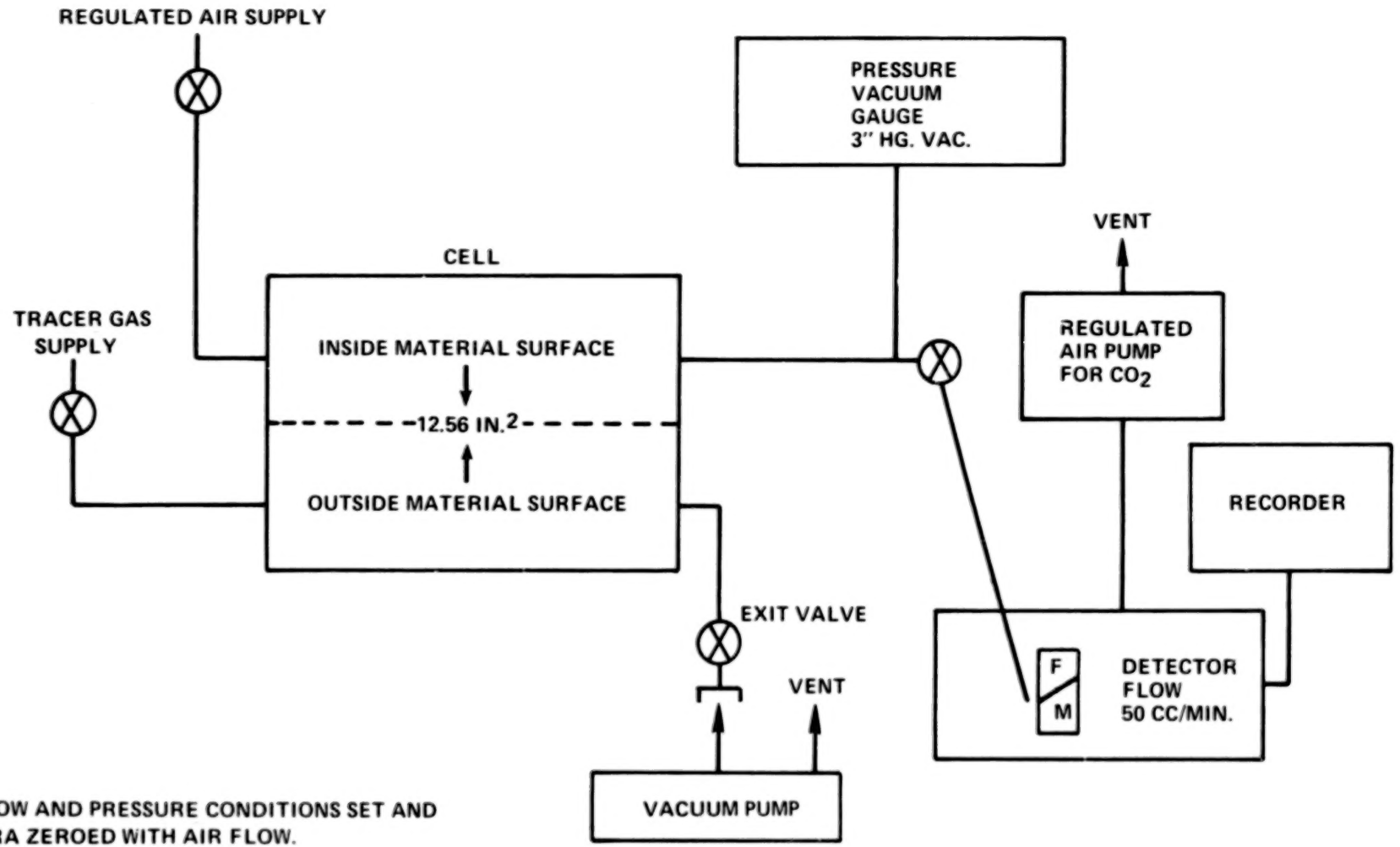
The MMH test was conducted under "worst case" conditions of: 100% concentration of the MMH, no or little pressure differential across the material, and minimal flow through the cell when dynamic testing (234 cc/min). These results indicate that a high degree of protection against MMH is provided to the wearer of a suit made of the present material.

BIBLIOGRAPHY

1. NASA Report "SCAPE Suit Permeation Model," Peter J. Welch, February 6, 1978.

2. NASA TMX-68188 "A Method for Defining Down Wind Evacuation Areas for Transportation Accidents Involving Toxic Propellants Spills."

CELL TEST APPARATUS



FLOW AND PRESSURE CONDITIONS SET AND LIRA ZEROED WITH AIR FLOW.

AIR REMOVED FROM LOWER CHAMBER AND CO_2 FLOW ESTABLISHED.
FLUSH WITH CO_2 5 MINUTES. SECURE SUPPLY VALVE THEN EXIT VALVE.
1 ATM CO_2 IN LOWER CELL.

SAME SEQUENCE FOLLOWED WITH ECOLYZER AND N_2O_4 SUPPLY AFTER CO_2 RUN.
"INTERNAL PUMP USED"

FIGURE 1.

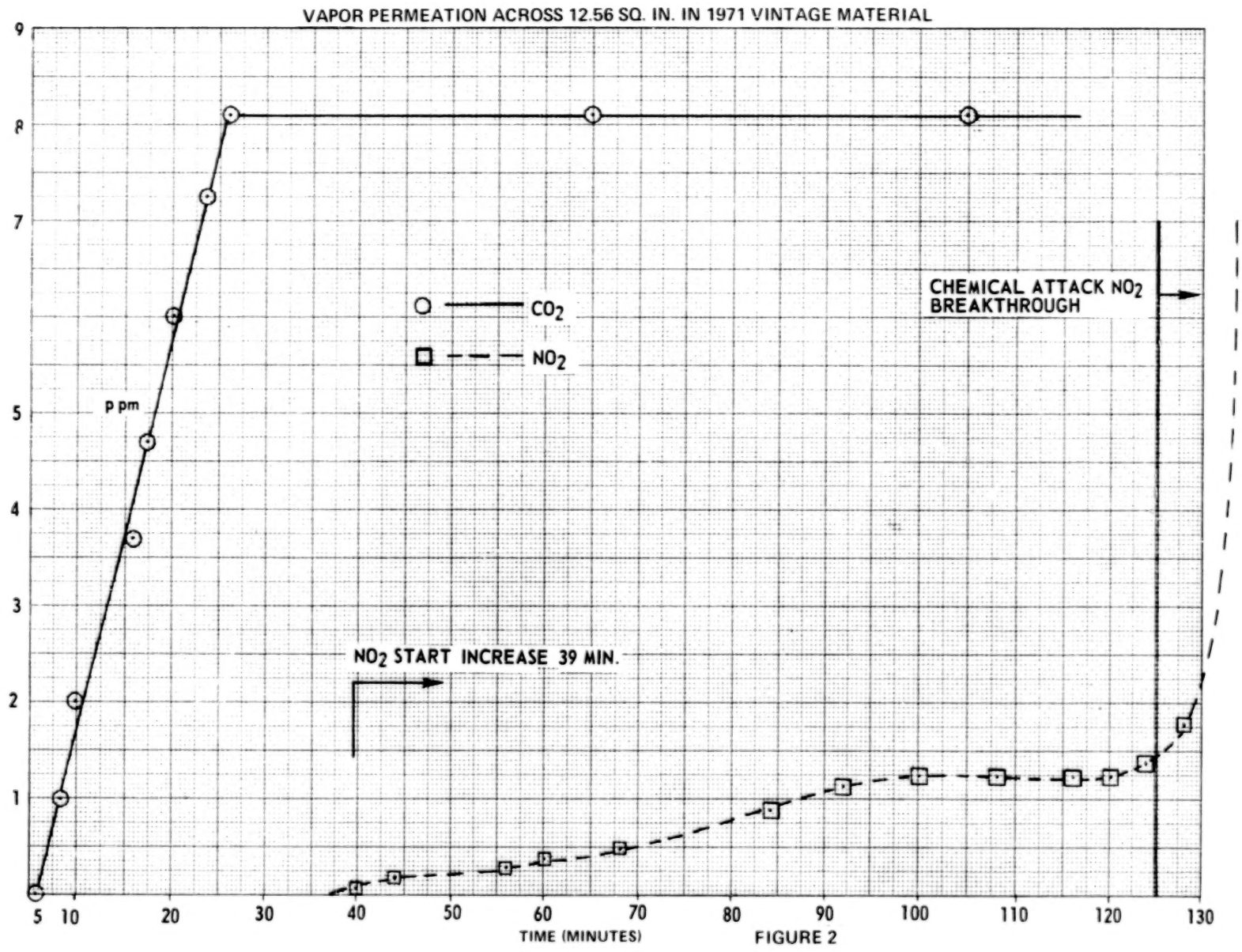

VAPOR PERMEATION ACROSS 12.56 SQ. IN. IN 1971 VINTAGE MATERIAL
9
8
7
5
4
3
2
1
p pm
CO2
NO2
CHEMICAL ATTACK NO2 BREAKTHROUGH
NO2 START INCREASE 39 MIN.
5 10 20 30 40 50 60 70 80 90 100 110 120 130
TIME (MINUTES)

FIGURE 2

SCHEMATIC OF VALVE TESTING CELL

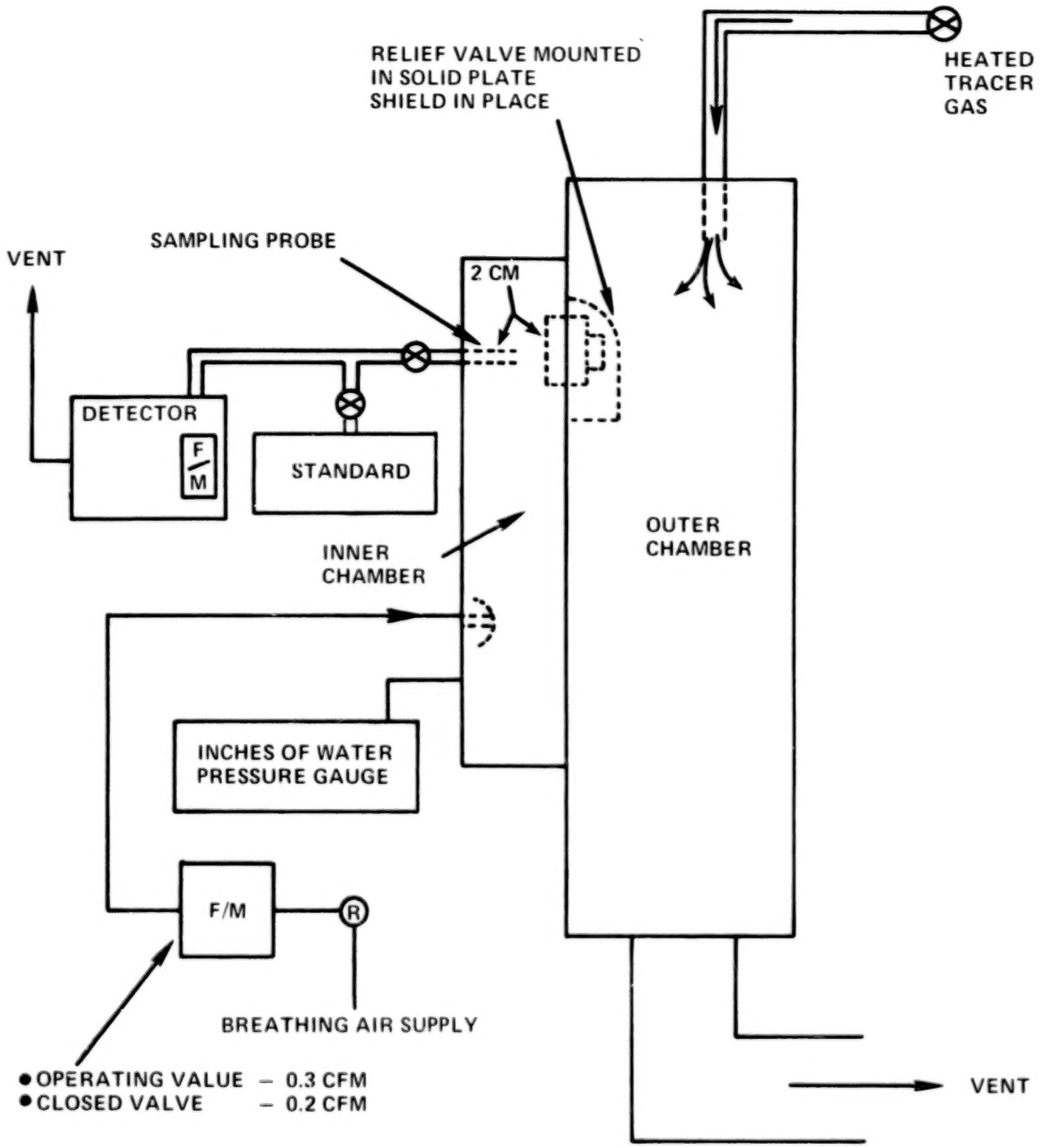
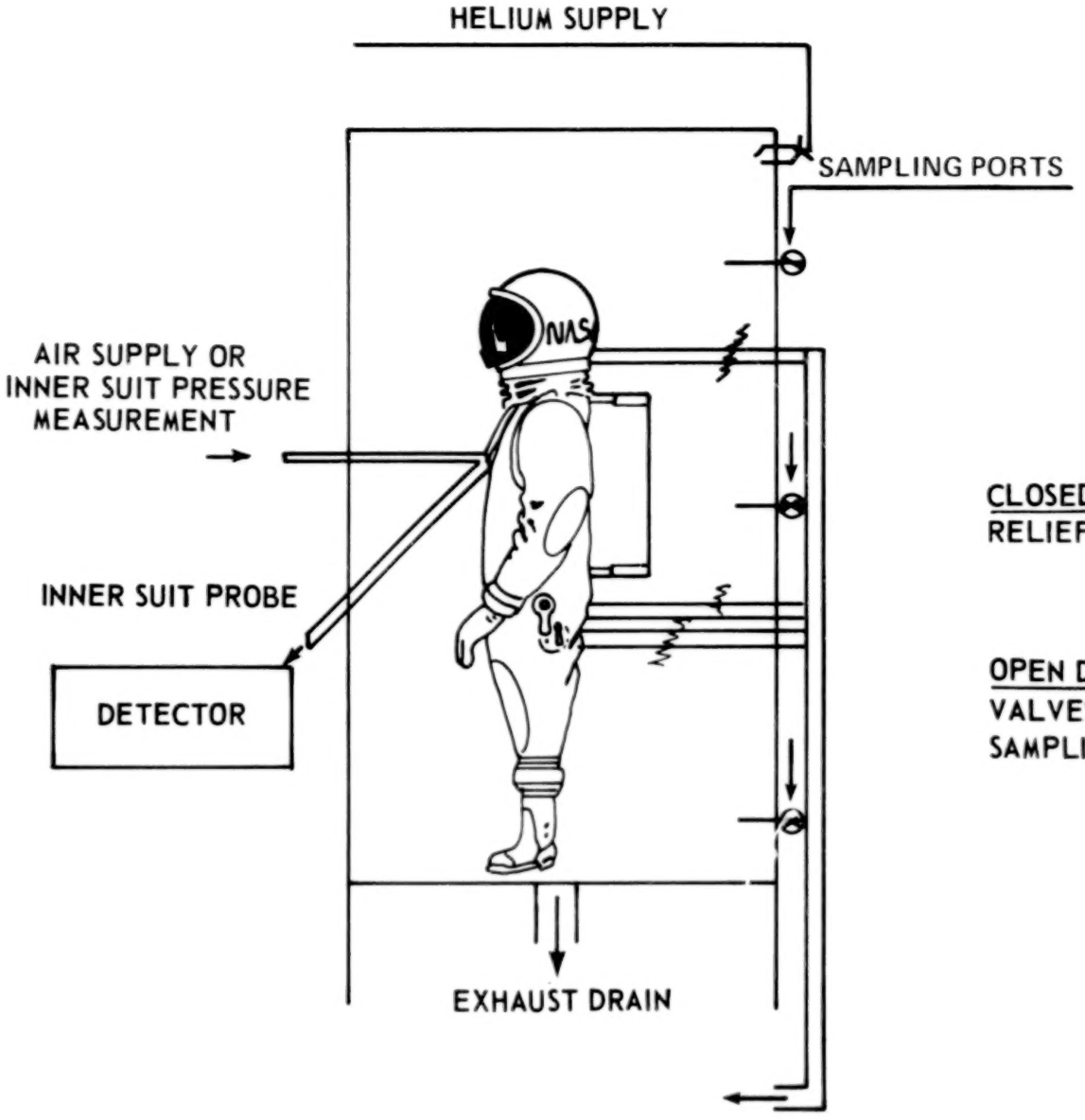


FIGURE 3.

SEALED CHAMBER SCAPE SUIT TEST



CLOSED LOOP TESTING – EXHAUST OF SUIT RELIEF VALVES EXTERIOR OF CHAMBER.

OPEN DUMP– HOSES REMOVED FROM SUIT RELIEF VALVES – EXHAUST DIRECTLY INTO CHAMBER. SAMPLING PROBE IN HELMET.

FIGURE 4.

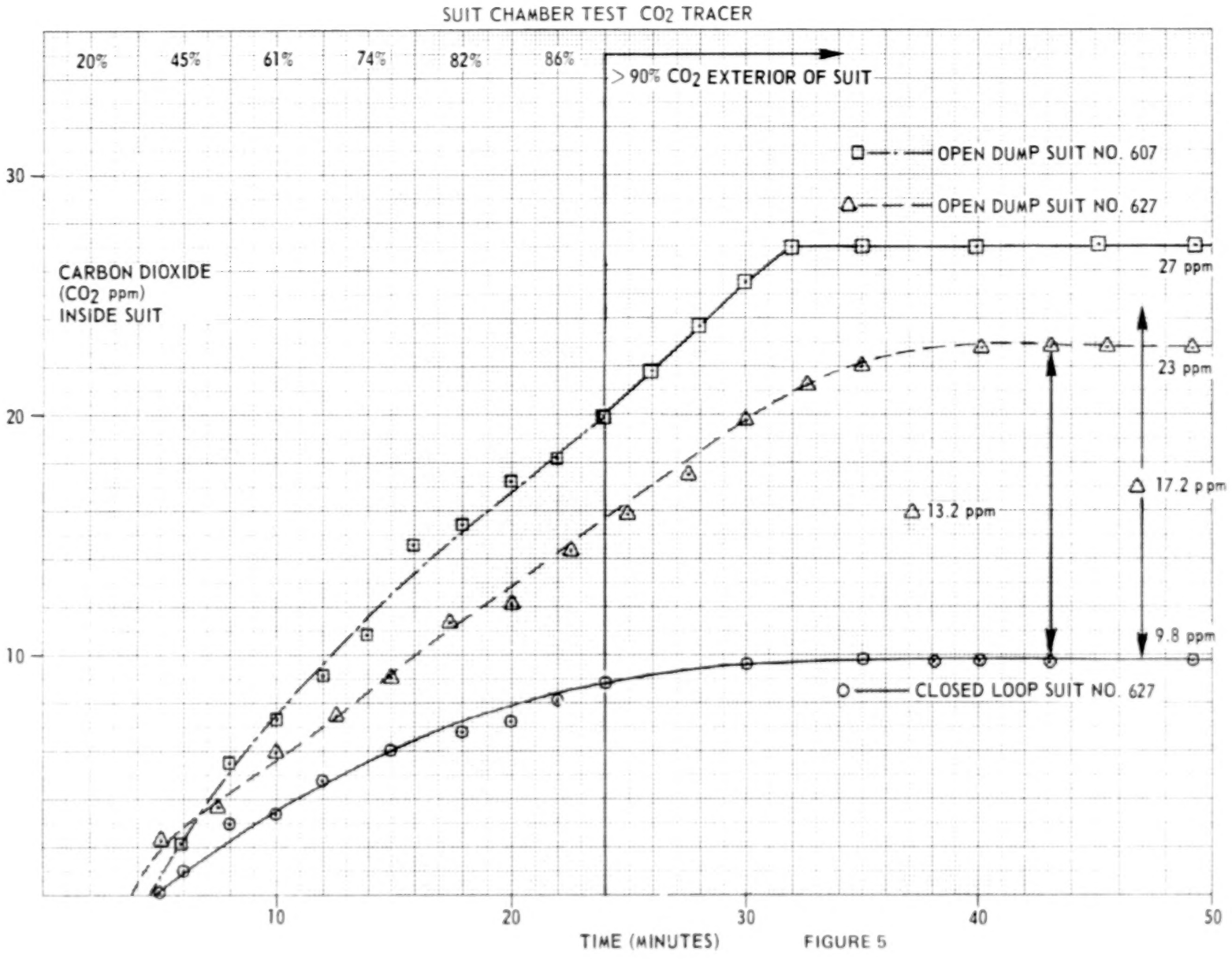

SUIT CHAMBER TEST CO_2 TRACER
20%
45%
61%
74%
82%
86%
> 90% CO_2 EXTERIOR OF SUIT
OPEN DUMP SUIT NO. 607
OPEN DUMP SUIT NO. 627
CARBON DIOXIDE
(CO_2 ppm)
INSIDE SUIT
27 ppm
23 ppm
17.2 ppm
13.2 ppm
9.8 ppm
CLOSED LOOP SUIT NO. 627
30
20
10
10
20
30
40
50
TIME (MINUTES)

FIGURE 5

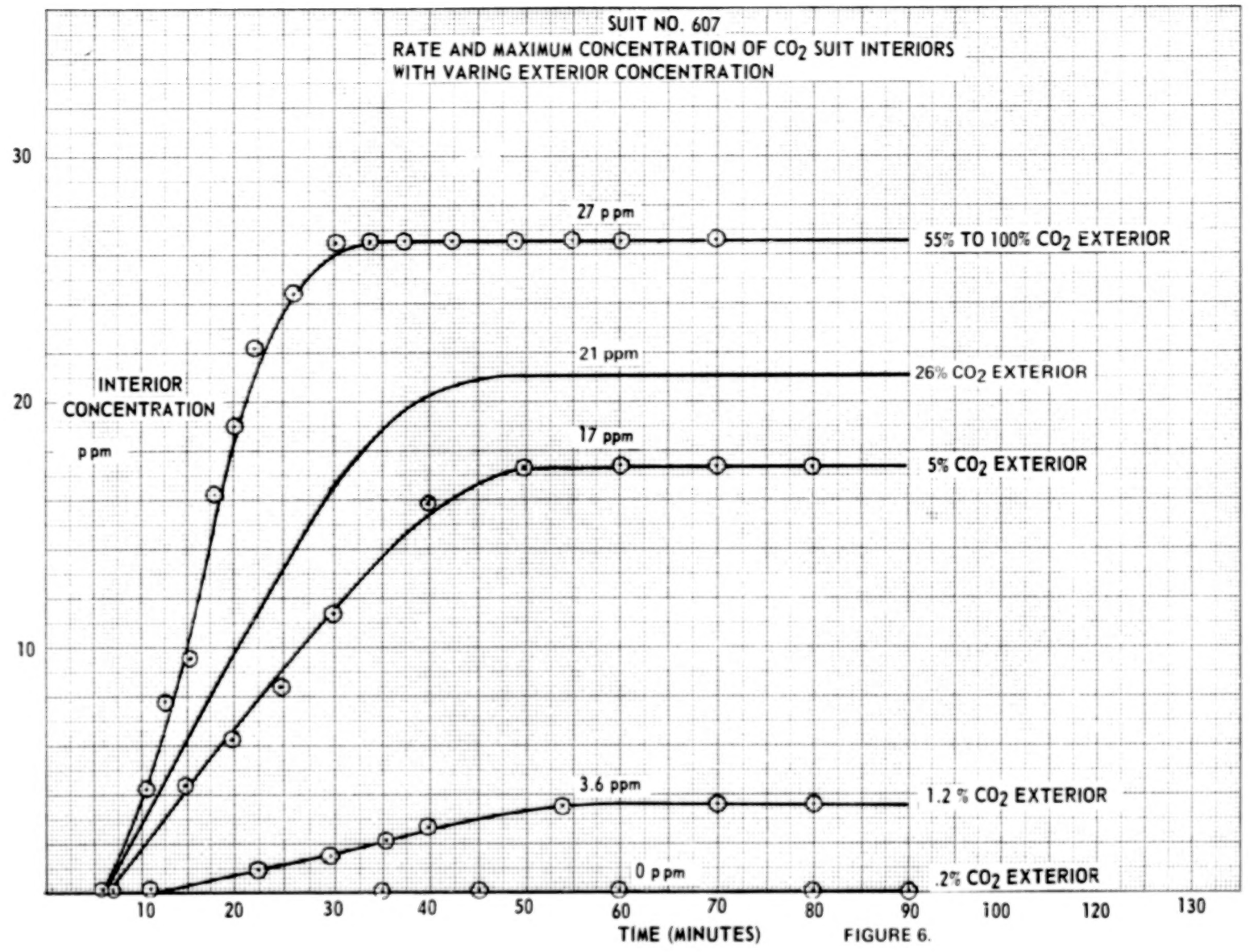
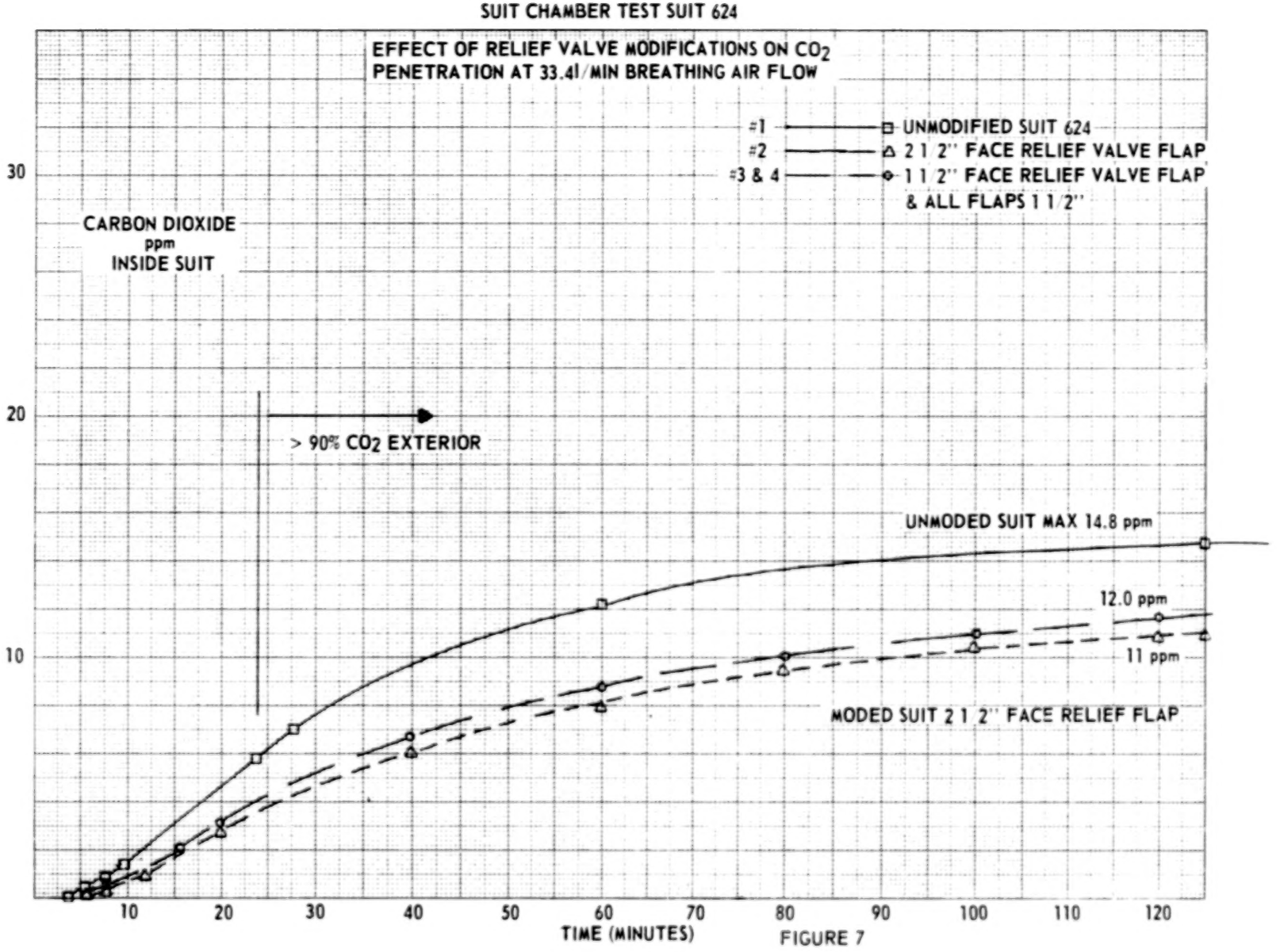
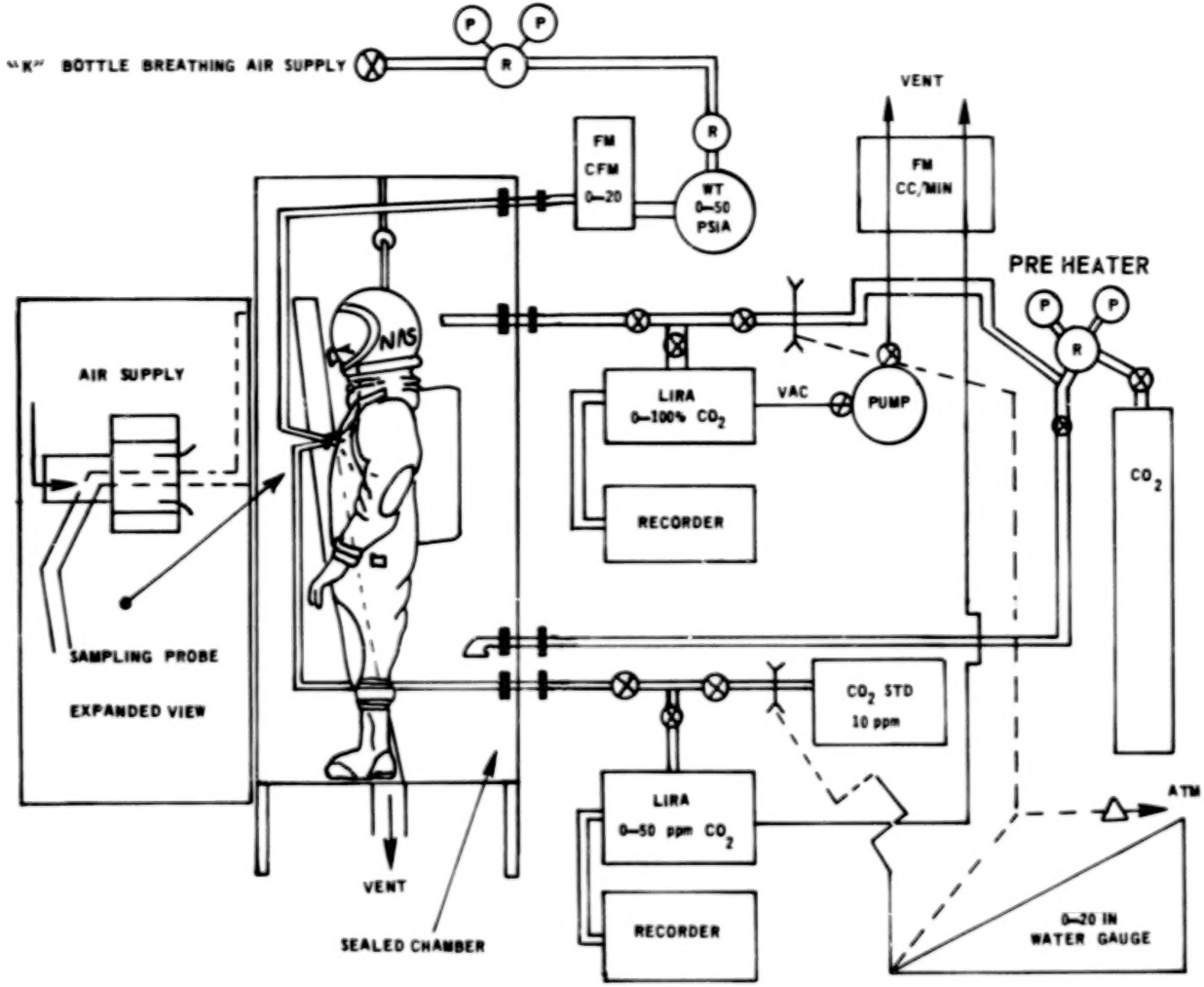

SUIT NO. 607
RATE AND MAXIMUM CONCENTRATION OF CO_2 SUIT INTERIORS
WITH VARING EXTERIOR CONCENTRATION
INTERIOR CONCENTRATION
p pm
30
20
10
27 p pm
55% TO 100% CO_2 EXTERIOR
21 ppm
26% CO_2 EXTERIOR
17 ppm
5% CO_2 EXTERIOR
3.6 ppm
1.2 % CO_2 EXTERIOR
0 p pm
.2% CO_2 EXTERIOR
10
20
30
40
50
60
70
80
90
100
120
130
TIME (MINUTES)

FIGURE 6.


SUIT CHAMBER TEST SUIT 624
EFFECT OF RELIEF VALVE MODIFICATIONS ON CO_2 PENETRATION AT 33.4 l/MIN BREATHING AIR FLOW
#1 UNMODIFIED SUIT 624
#2 2 1 2" FACE RELIEF VALVE FLAP
#3 & 4 1 1 2" FACE RELIEF VALVE FLAP & ALL FLAPS 1 1 2"
CARBON DIOXIDE ppm INSIDE SUIT
30
20
10
> 90% CO_2 EXTERIOR
UNMODED SUIT MAX 14.8 ppm
12.0 ppm
11 ppm
MODED SUIT 2 1 2" FACE RELIEF FLAP
10 20 30 40 50 60 70 80 90 100 110 120
TIME (MINUTES)
FIGURE 7



SCAPE SUIT
CARBON DIOXIDE PENETRATION ANALYSIS
TEST APPRATUS
FIGURE 8

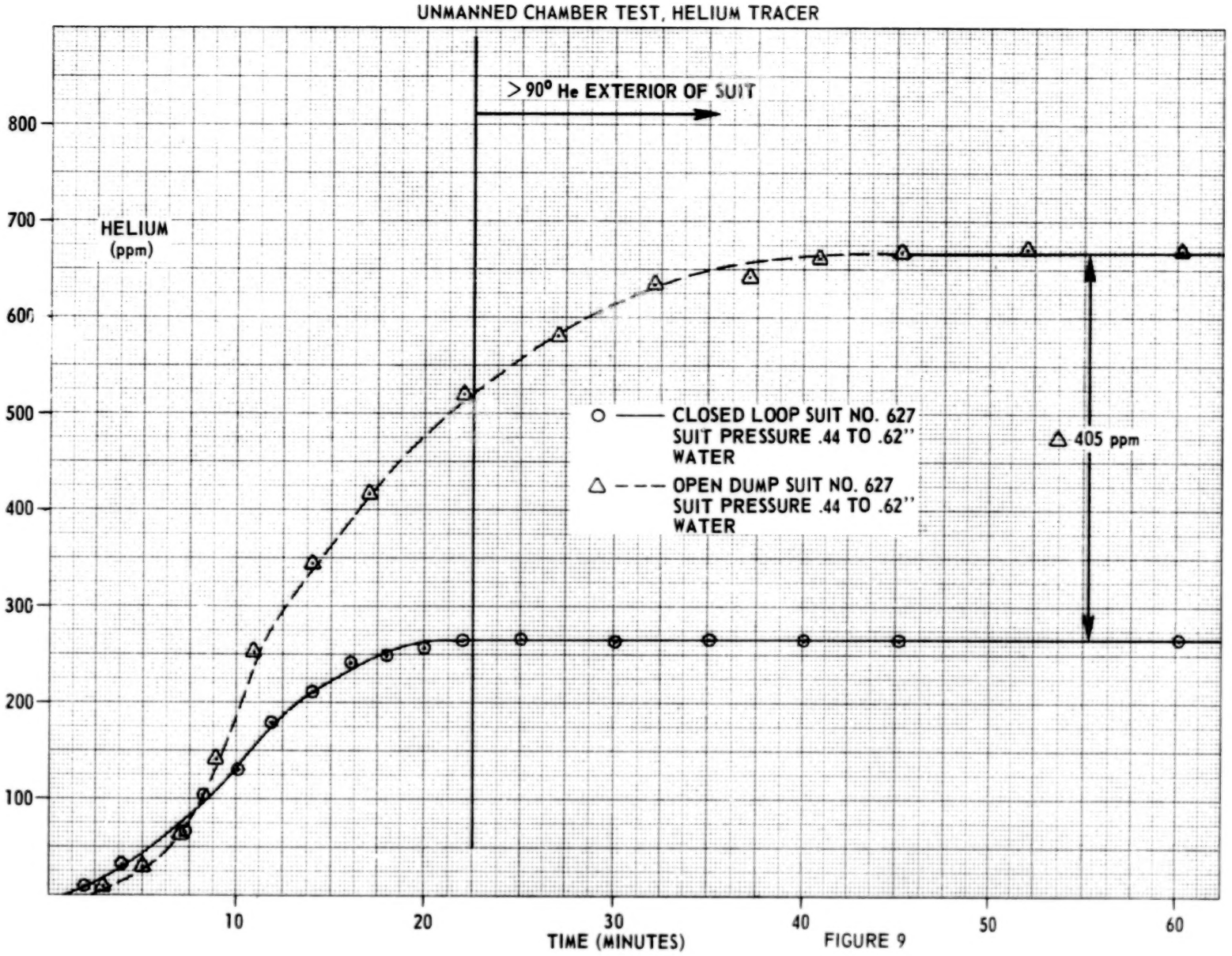

UNMANNED CHAMBER TEST, HELIUM TRACER
>90° He EXTERIOR OF SUIT
HELIUM
(ppm)
800
700
600
500
400
300
200
100
10
20
30
40
50
60
TIME (MINUTES)
○ —— CLOSED LOOP SUIT NO. 627
SUIT PRESSURE .44 TO .62"
WATER
△ - - - OPEN DUMP SUIT NO. 627
SUIT PRESSURE .44 TO .62"
WATER
△ 405 ppm

FIGURE 9

MANNED AND UNMANNED CHAMBER TEST, HELIUM TRACER

CELL WITH TESTING EQUIPMENT SCHEMATIC

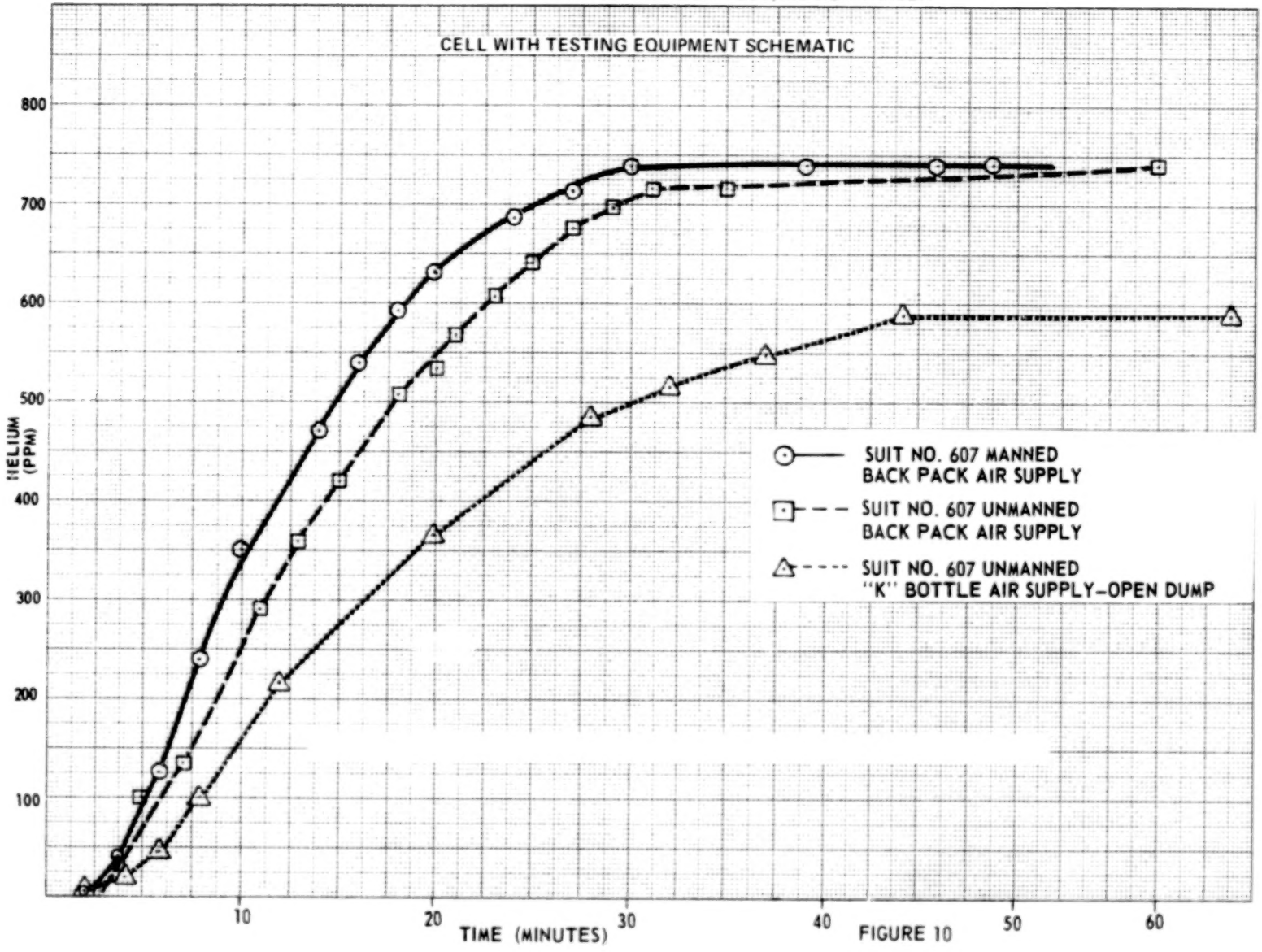


FIGURE 10

CHAMBER TEST UNMANNED MODIFIED SUIT

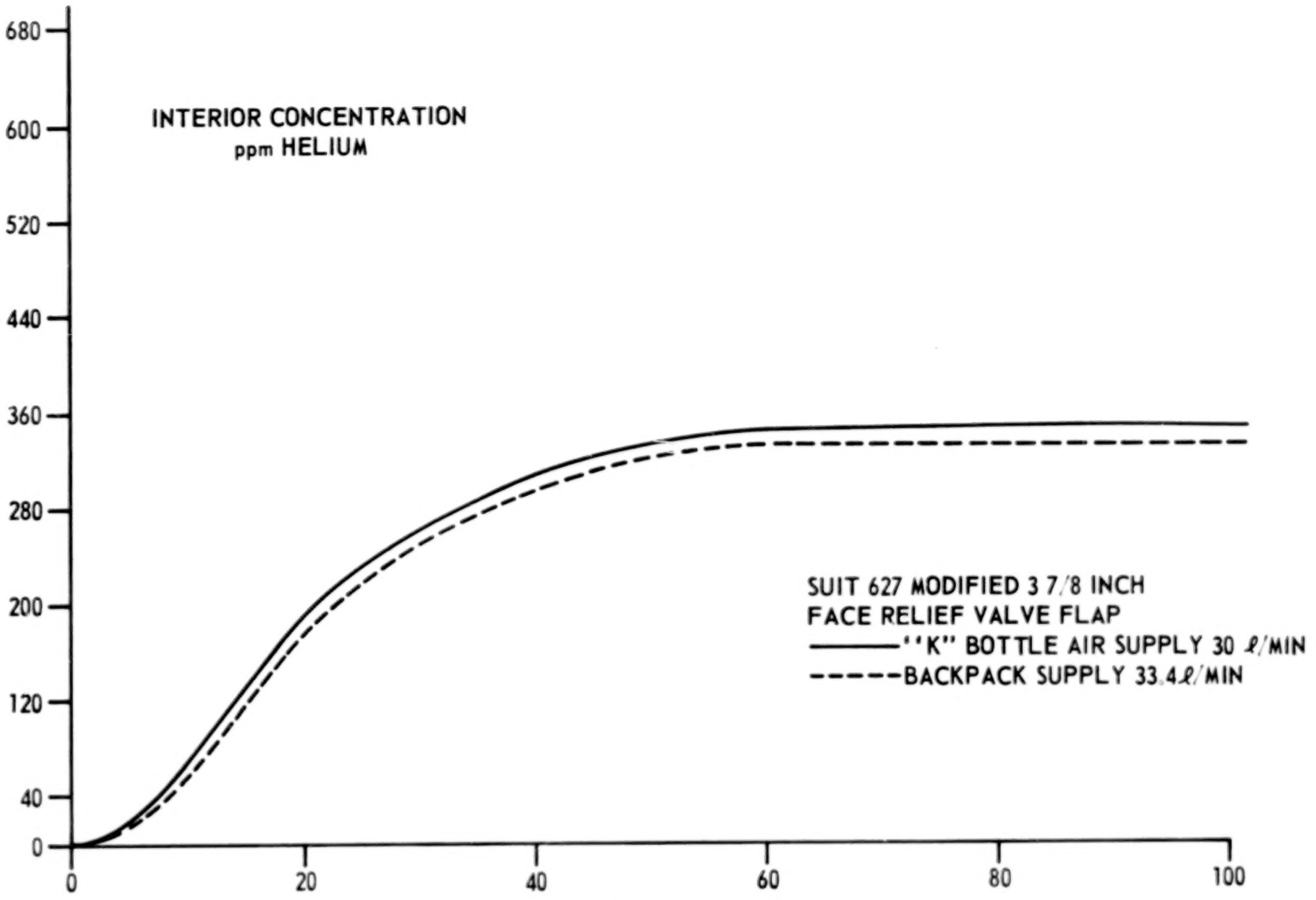


FIGURE 11

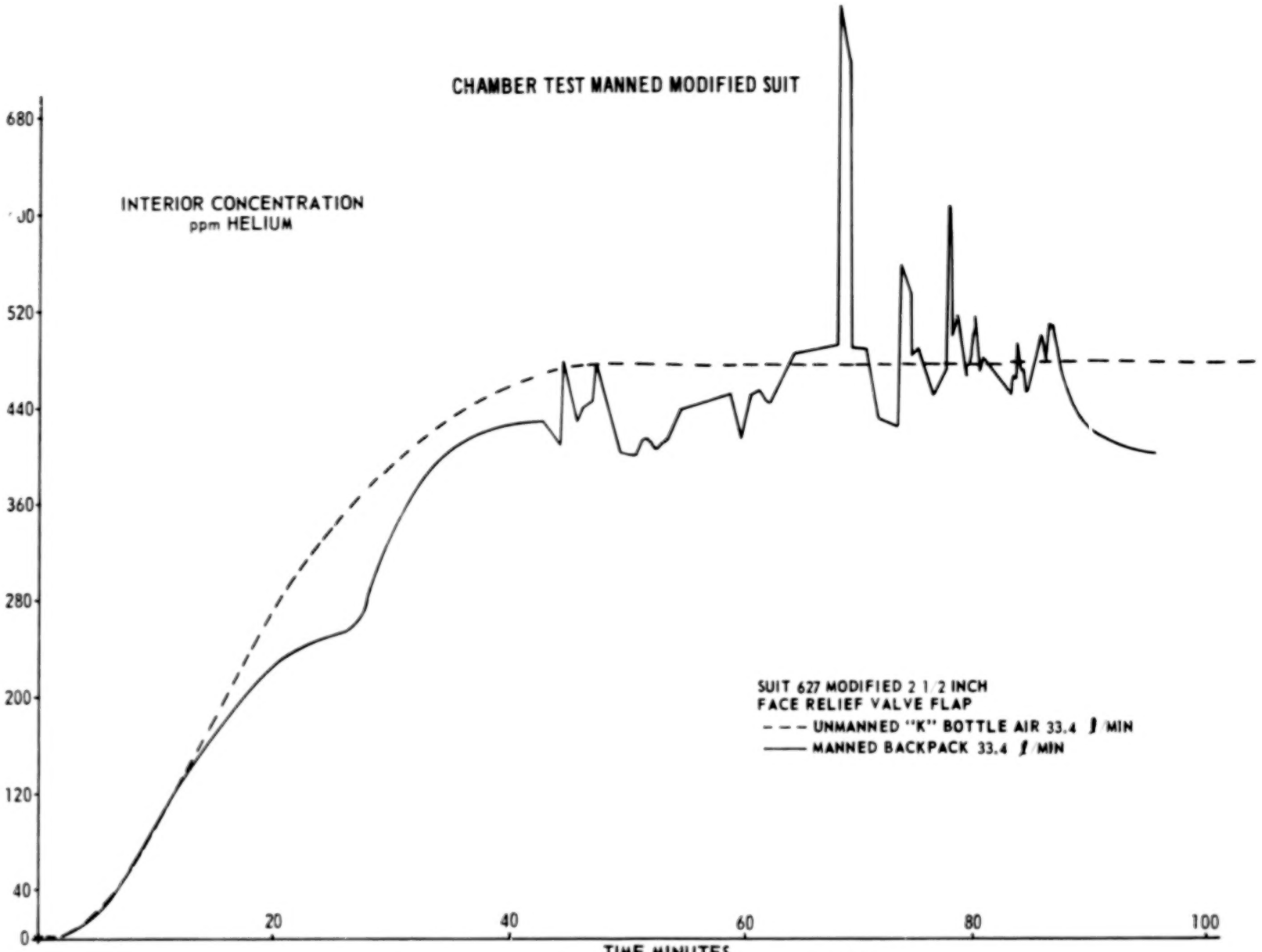

CHAMBER TEST MANNED MODIFIED SUIT
INTERIOR CONCENTRATION
ppm HELIUM
680
520
440
360
280
200
120
40
0
20
40
60
80
100
TIME MINUTES
SUIT 627 MODIFIED 2 1/2 INCH
FACE RELIEF VALVE FLAP
- - - UNMANNED "K" BOTTLE AIR 33.4 ℓ/MIN
—— MANNED BACKPACK 33.4 ℓ/MIN

FIGURE 12

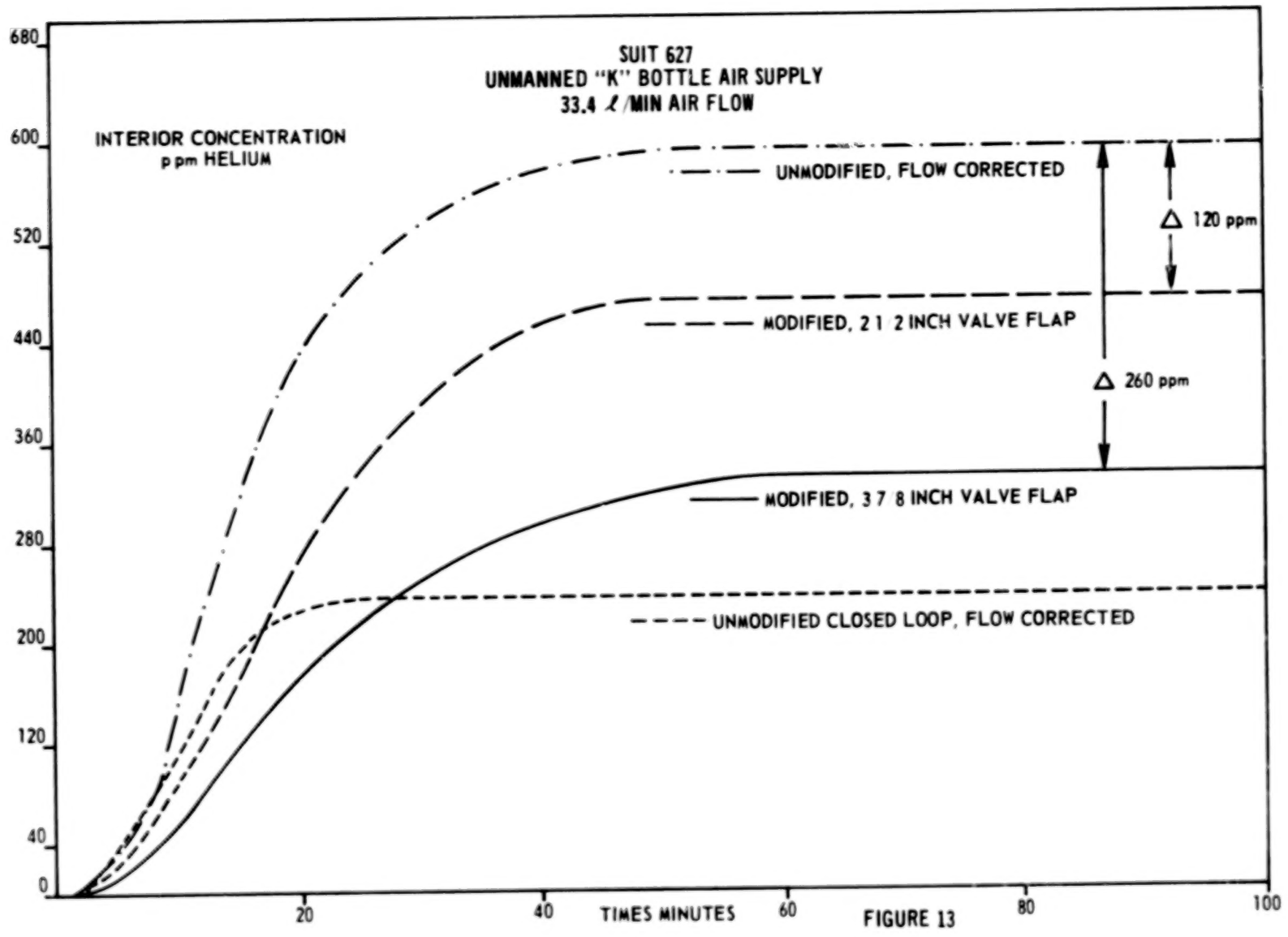

SUIT 627
UNMANNED "K" BOTTLE AIR SUPPLY
33.4 ℓ /MIN AIR FLOW
INTERIOR CONCENTRATION
p pm HELIUM
UNMODIFIED, FLOW CORRECTED
MODIFIED, 2 1/2 INCH VALVE FLAP
MODIFIED, 3 7/8 INCH VALVE FLAP
UNMODIFIED CLOSED LOOP, FLOW CORRECTED
Δ 120 ppm
Δ 260 ppm
680
600
520
440
360
280
200
120
40
0
20
40
60
80
100
TIMES MINUTES

FIGURE 13

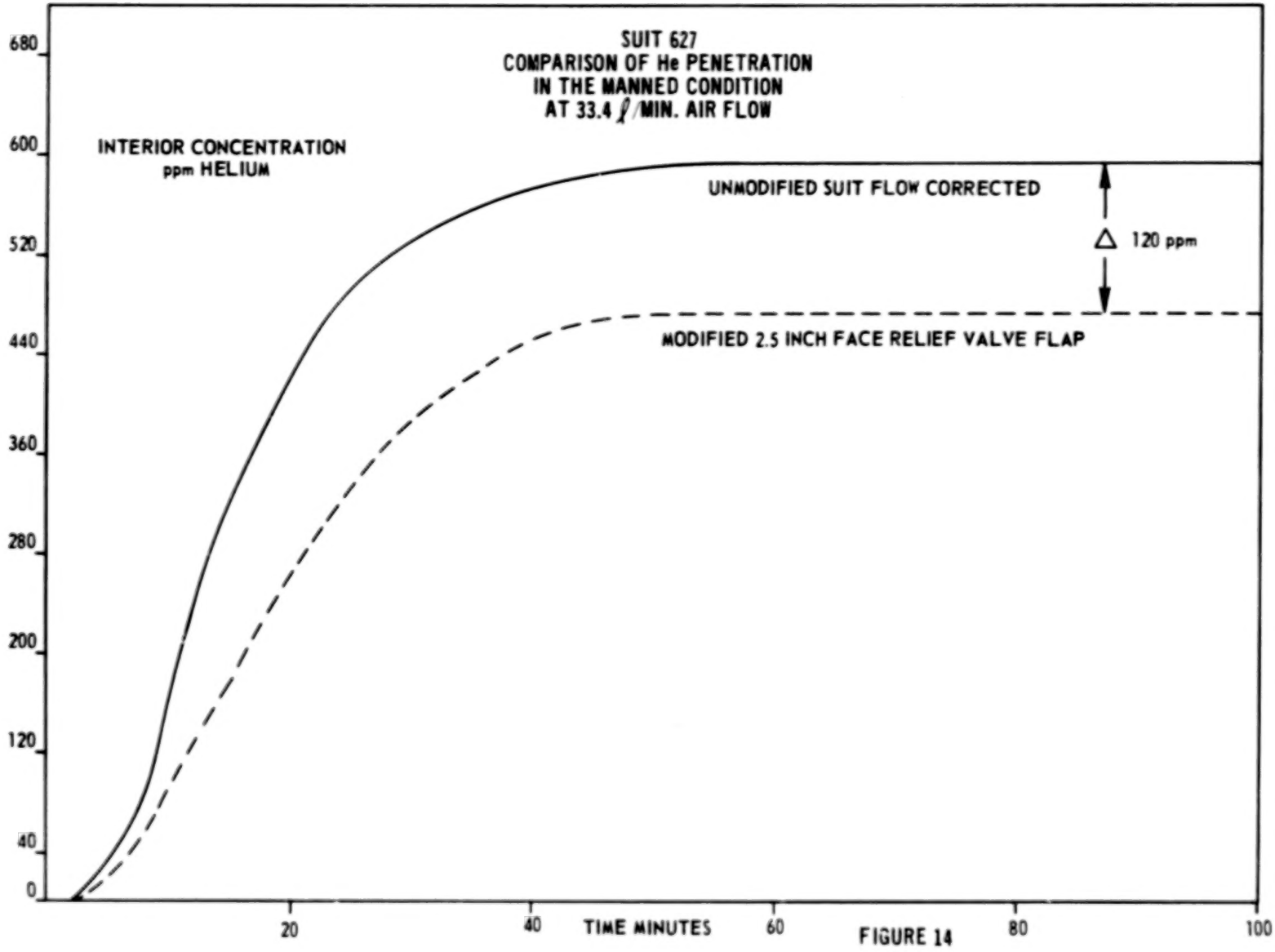

SUIT 627
COMPARISON OF He PENETRATION
IN THE MANNED CONDITION
AT 33.4 ℓ/MIN. AIR FLOW
INTERIOR CONCENTRATION
ppm HELIUM
UNMODIFIED SUIT FLOW CORRECTED
Δ 120 ppm
MODIFIED 2.5 INCH FACE RELIEF VALVE FLAP
680
600
520
440
360
280
200
120
40
0
20
40
60
80
100
TIME MINUTES

FIGURE 14

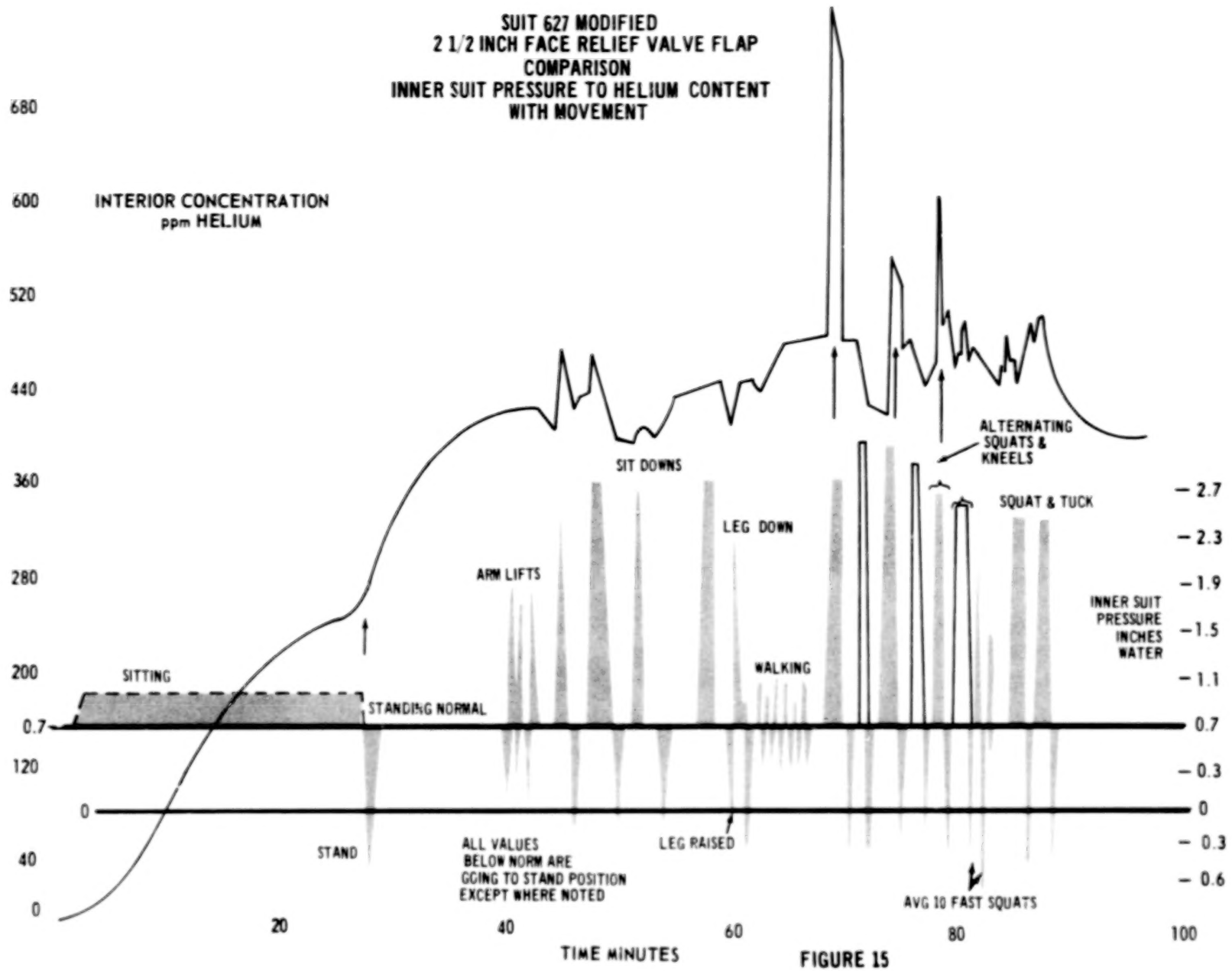
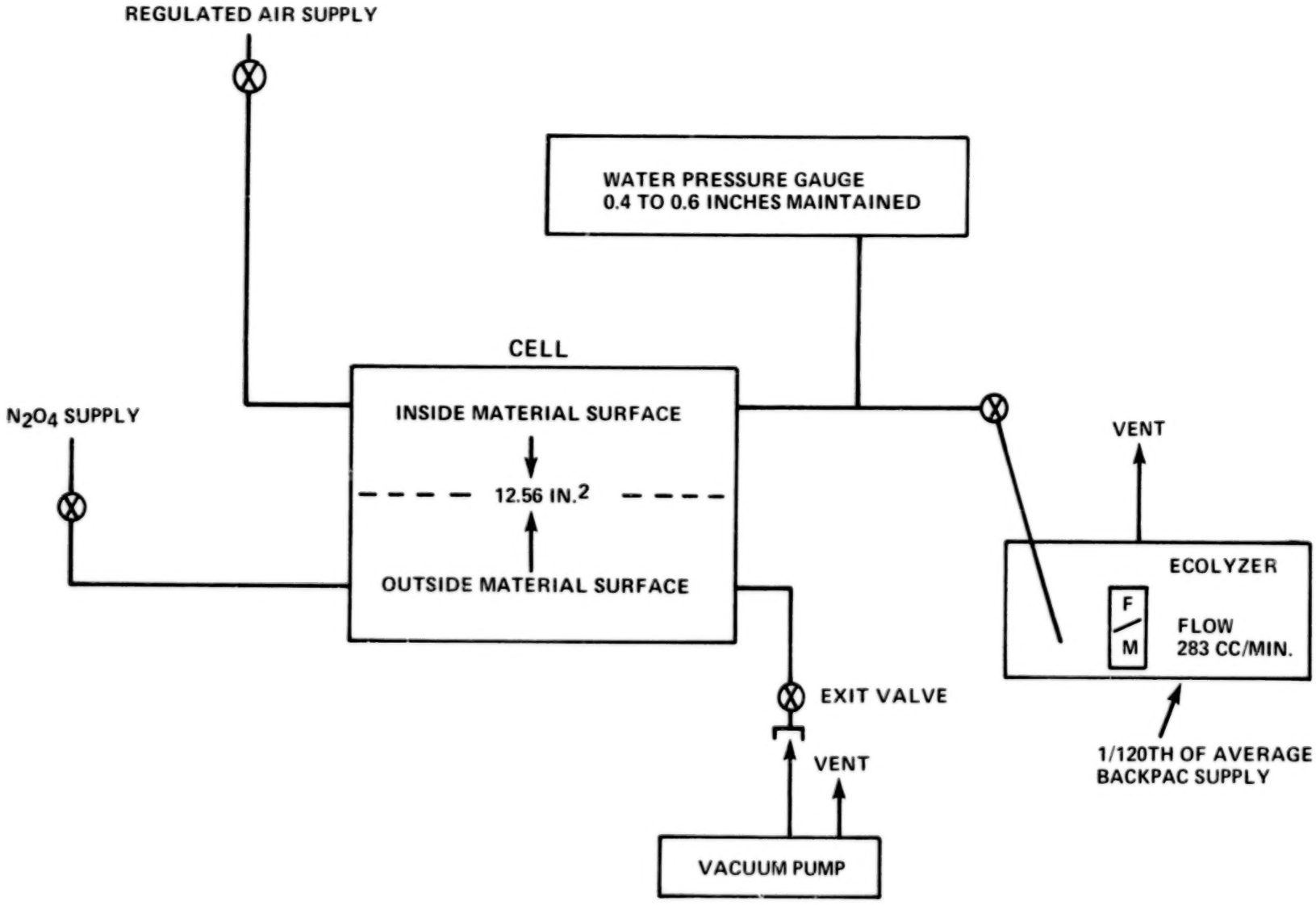

SUIT 627 MODIFIED
2 1/2 INCH FACE RELIEF VALVE FLAP
COMPARISON
INNER SUIT PRESSURE TO HELIUM CONTENT
WITH MOVEMENT
INTERIOR CONCENTRATION
ppm HELIUM
680
600
520
440
360
280
200
0.7
120
0
40
0
SITTING
STANDING NORMAL
STAND
ARM LIFTS
SIT DOWNS
LEG DOWN
WALKING
ALTERNATING
SQUATS &
KNEELS
SQUAT & TUCK
LEG RAISED
ALL VALUES
BELOW NORM ARE
GOING TO STAND POSITION
EXCEPT WHERE NOTED
AVG 10 FAST SQUATS
INNER SUIT
PRESSURE
INCHES
WATER
2.7
2.3
1.9
1.5
1.1
0.7
0.3
0
0.3
0.6
20
40
60
80
100
TIME MINUTES

FIGURE 15

NO_2 CELL TEST APPARATUS



FLOW AND PRESSURE CONDITIONS SET AND ECOLYZER ZEROED WITH AIR FLOW.

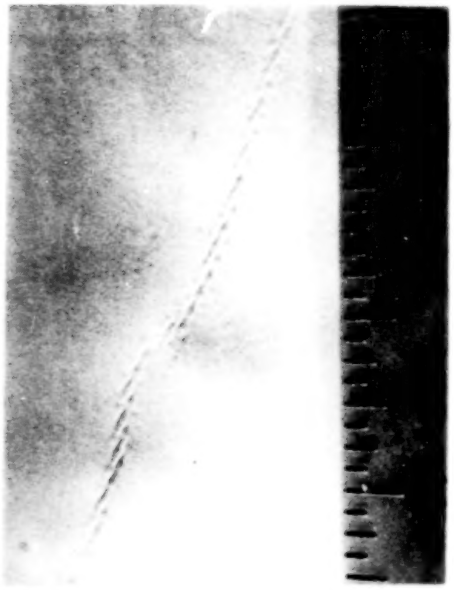
AIR REMOVED FROM LOWER CHAMBER AND N_2O_4 FLOW ESTABLISHED.
FLUSH WITH N_2O_4 5 MINUTES. SECURE SUPPLY VALVE THEN EXIT VALVE.
1 ATM N_2O_4 IN LOWER CELL.

FIGURE 16

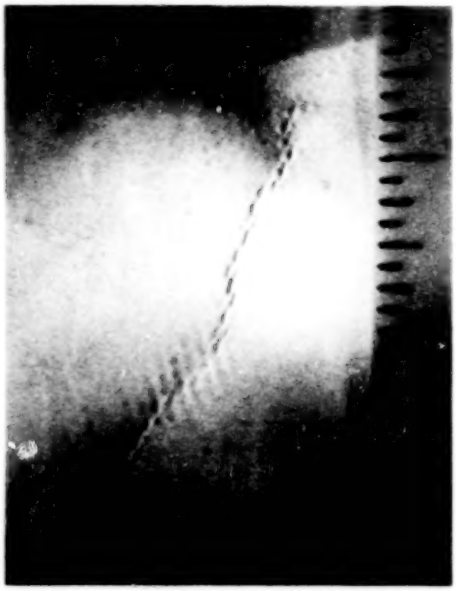
SAMPLE = 6
TUNNEL AND CREASING

INSIDE SURFACE

BEFORE EXPOSURE

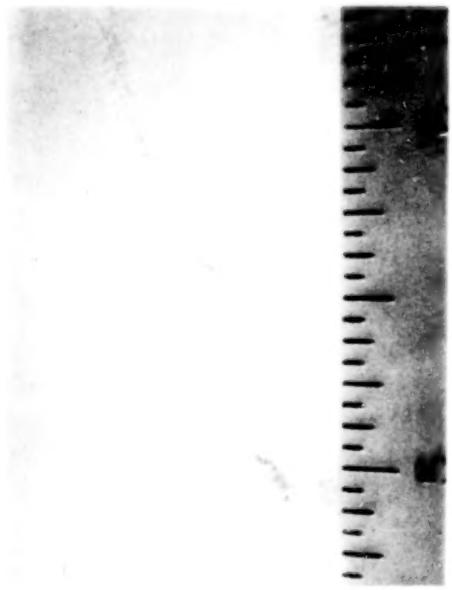


AFTER 2 HR. VAPOR EXPOSURE



OUTSIDE SURFACE

BEFORE EXPOSURE



AFTER EXPOSURE

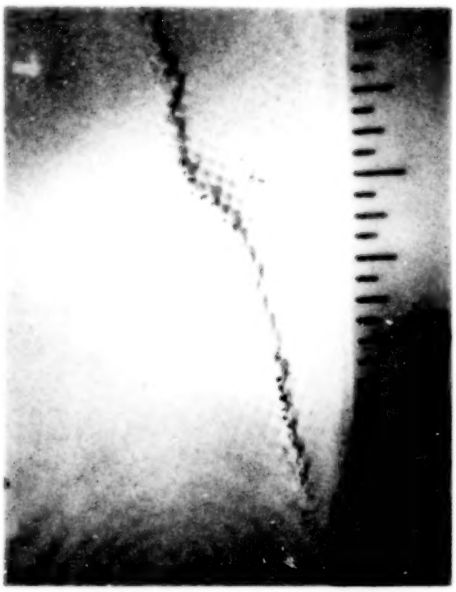
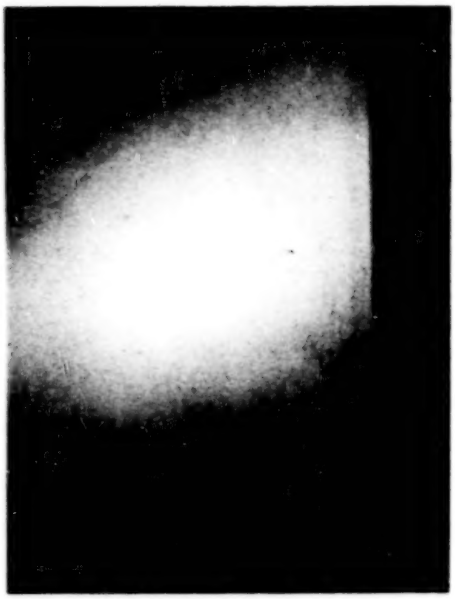


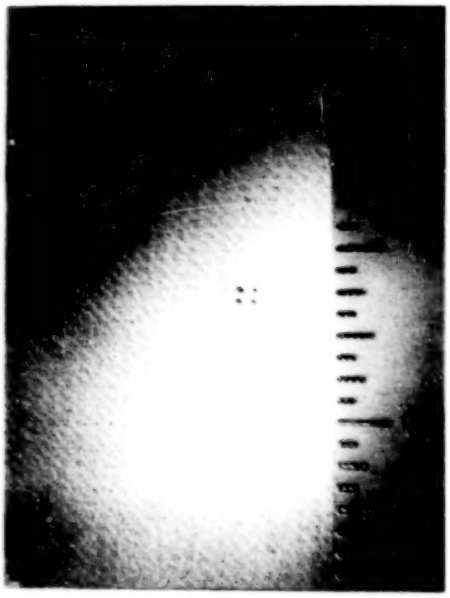
FIGURE 17

SAMPLE = 14
EXPOSED "NOMEX"

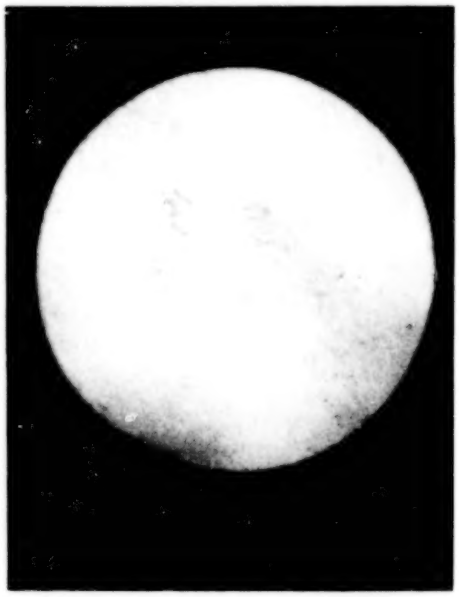
BEFORE EXPOSURE 2.5X



AFTER EXPOSURE 2.5 X



BEFORE EXPOSURE 15X



AFTER EXPOSURE 15X

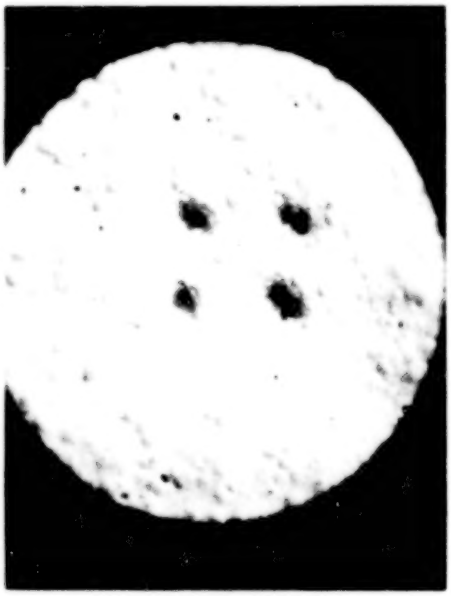
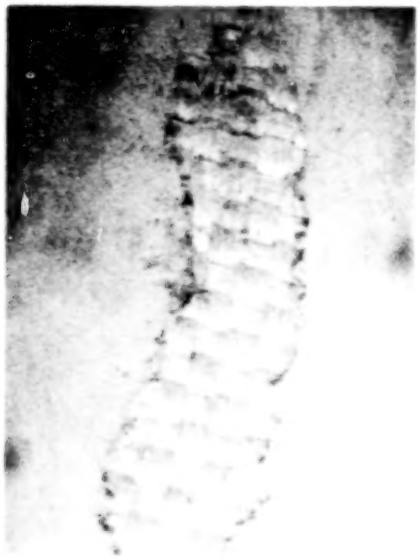


FIGURE 18

SAMPLE = 8
EXPOSED "NONEX"

OUTSIDE BEFORE EXPOSURE



OUTSIDE AFTER EXPOSURE

INSIDE BEFORE

INSIDE AFTER

FIGURE 19

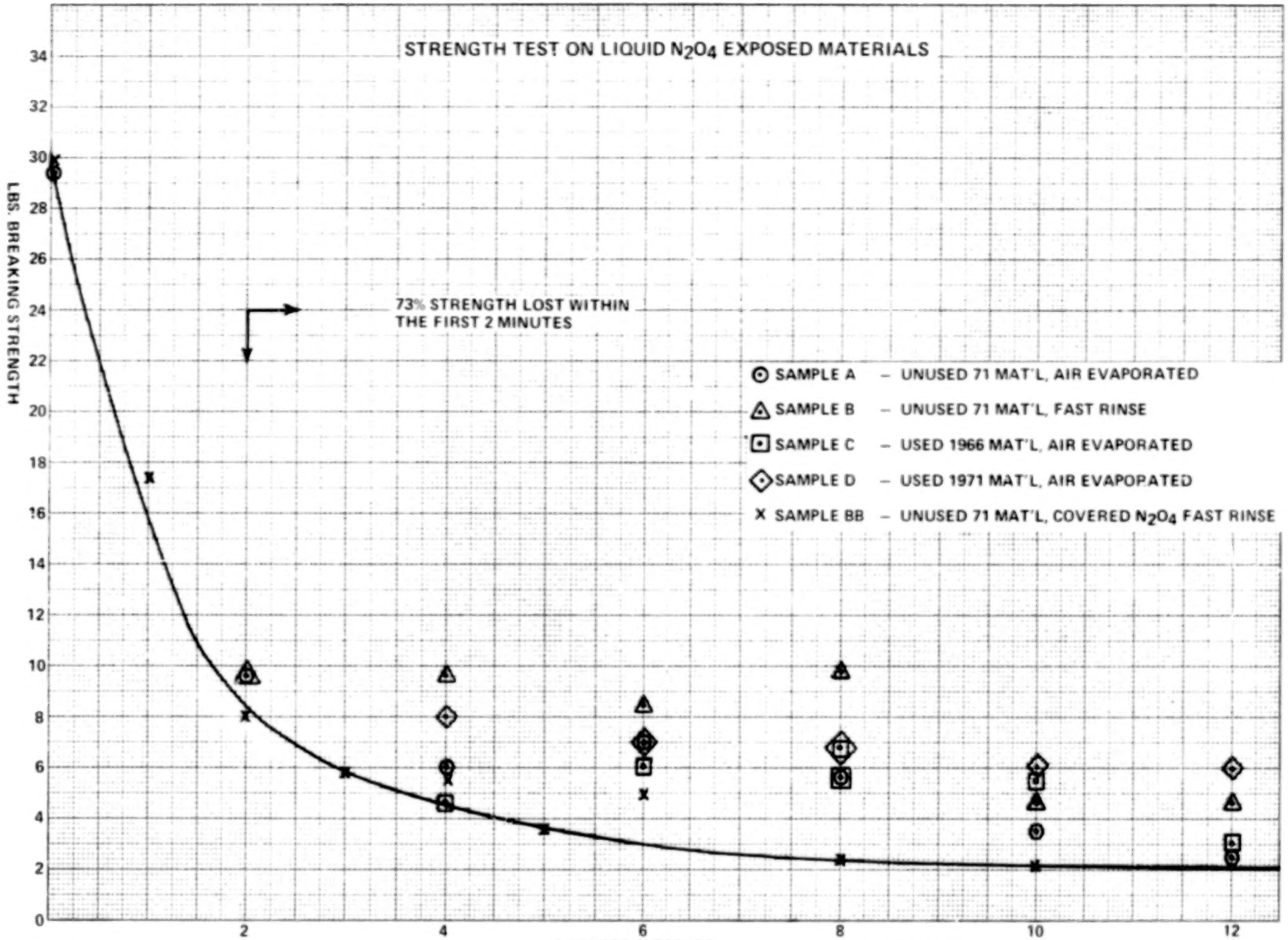

STRENGTH TEST ON LIQUID N_2O_4 EXPOSED MATERIALS
LBS. BREAKING STRENGTH
MINUTES EXPOSURE
73% STRENGTH LOST WITHIN THE FIRST 2 MINUTES
SAMPLE A – UNUSED 71 MAT'L, AIR EVAPORATED
SAMPLE B – UNUSED 71 MAT'L, FAST RINSE
SAMPLE C – USED 1966 MAT'L, AIR EVAPORATED
SAMPLE D – USED 1971 MAT'L, AIR EVAPOPATED
SAMPLE BB – UNUSED 71 MAT'L, COVERED N_2O_4 FAST RINSE
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34

FIGURE 20

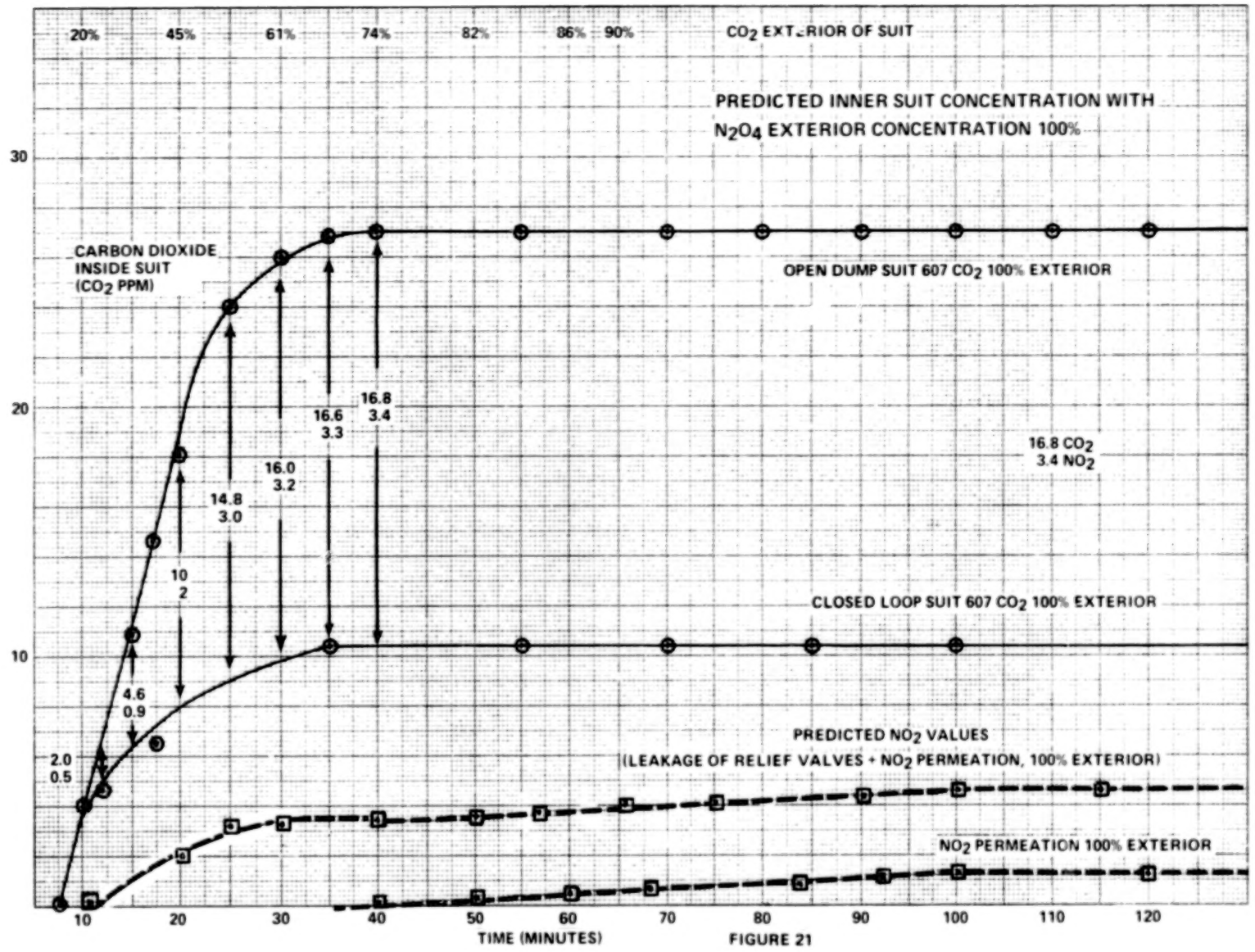

20%
45%
61%
74%
82%
86%
90%
CO_2 EXTERIOR OF SUIT
PREDICTED INNER SUIT CONCENTRATION WITH
N_2O_4 EXTERIOR CONCENTRATION 100%
30
20
10
CARBON DIOXIDE
INSIDE SUIT
(CO_2 PPM)
OPEN DUMP SUIT 607 CO_2 100% EXTERIOR
16.8
3.4
16.6
3.3
16.0
3.2
14.8
3.0
16.8 CO_2
3.4 NO_2
10
2
CLOSED LOOP SUIT 607 CO_2 100% EXTERIOR
4.6
0.9
2.0
0.5
PREDICTED NO_2 VALUES
(LEAKAGE OF RELIEF VALVES + NO_2 PERMEATION, 100% EXTERIOR)
NO_2 PERMEATION 100% EXTERIOR
10
20
30
40
50
60
70
80
90
100
110
120
TIME (MINUTES)

FIGURE 21

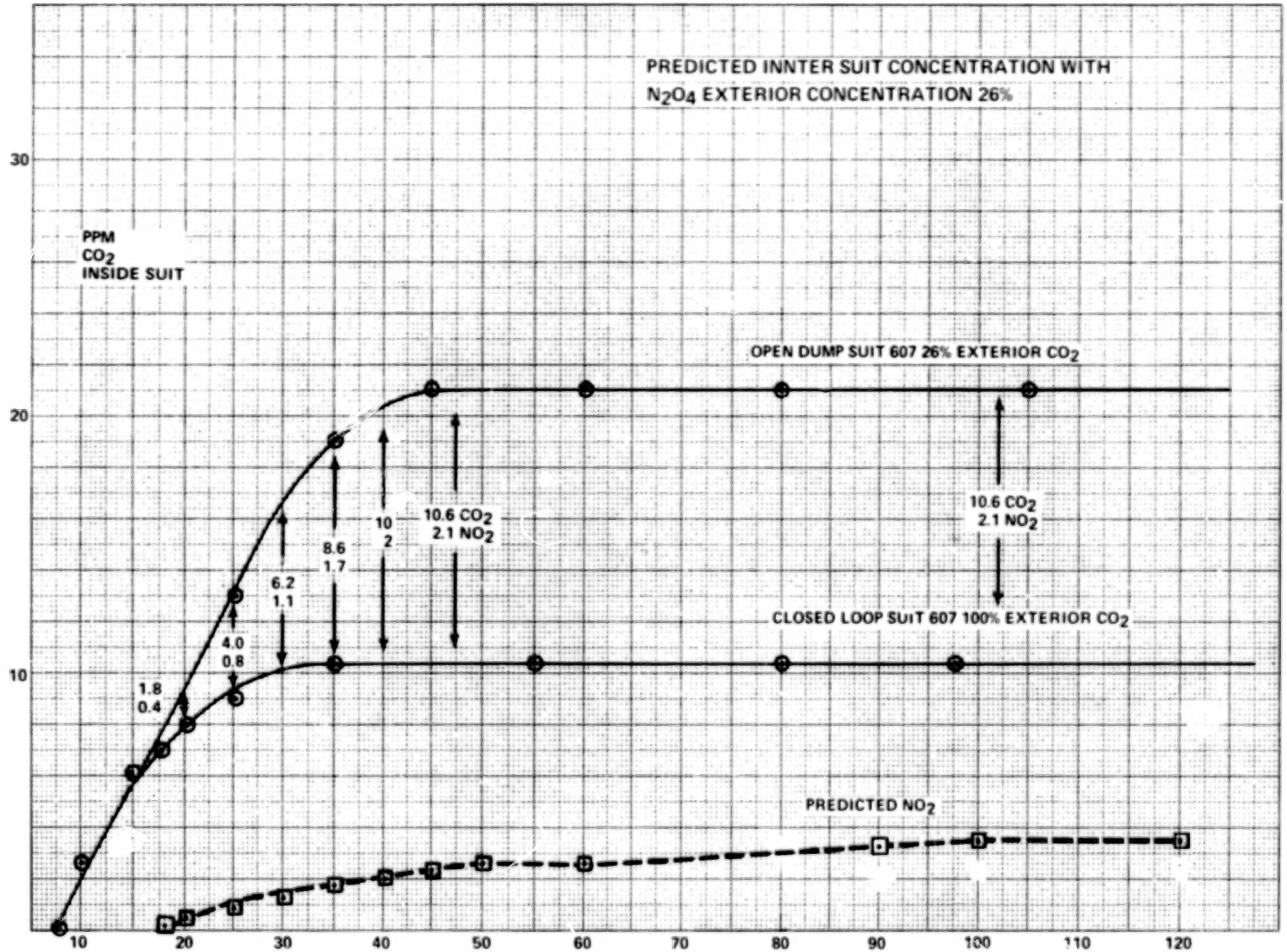

PREDICTED INNTER SUIT CONCENTRATION WITH
N_2O_4 EXTERIOR CONCENTRATION 26%
PPM
CO_2
INSIDE SUIT
30
20
10
OPEN DUMP SUIT 607 26% EXTERIOR CO_2
CLOSED LOOP SUIT 607 100% EXTERIOR CO_2
10.6 CO_2
2.1 NO_2
10
2
8.6
1.7
6.2
1.1
4.0
0.8
1.8
0.4
10.6 CO_2
2.1 NO_2
PREDICTED NO_2
10
20
30
40
50
60
70
80
90
100
110
120
TIME (MINUTES)

FIGURE 22

INTERIOR SUIT CONCENTRATION CHANGES WITH SELECTED MOVEMENTS

EXERCISE	HELIUM AT EQUILIBRIUM ppm	DURATION OF MOVEMENT MIN	PRESSURE INCHES OF WATER	HELIUM INCREASE ppm	HELIUM AS CO_2 ppm
ARM MOVEMENTS	739	3	0.32–0.6	0	0
SITTING UP & DOWN ACTION	739	2	0.32–0.6	0	0
LEG MOVEMENT IN SITTING POSITION	739	5	0.2 –0.7	0	0
SIMULATED NORMAL WALKING	739	3	0.2 –0.7	0	0
HIGH LEG MOVEMENT (GOOSE STEP)	739	1	0.0 –1.5	27	1
DEEP KNEE BEND STOOP & STAND	739	N/A	0.0 –1.9	41	1.5
1	NO	N/A	0.0 –2.5	81	3.0
2	NO	N/A	0.0 –2.7	81	3.0
3	NO	N/A	0.0 –3.0	216	8.0
4	START 820– FINISH 955	N/A	0.0 –2.6	135	5.0
5	START 820– FINISH 942	N/A	0.0 –2.7	122	4.5
6	START 928– FINISH 955	N/A	0.0 –2.8	27	1
MOTIONLESS	739	4 MIN	0.32–0.6	0	0

TABLE 1

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TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

TABLE 2

EFFECTS OF MOVEMENT

SUIT 627 – MODIFIED – 2 1/2 INCH FACE RELIEF VALVE FLAP

TIME (MIN) AFTER EXPOSURE	ACTION	INNER SUIT PRESSURE INCHES WATER	Δ ppm HELIUM
0	STANDING	0.7	
3 – 28	SIT DOWN	1.0	
28	STAND UP	–0.5	SLOW RISE
29	STATIONARY	0.7	
40	ARM LIFTS 3 MIN	0.1►1.9	LEVEL
43	STATIONARY	0.7	
45	SIT DOWN	2.7	40 ppm MAX. SLIGHT RISE
46	STAND UP	–0.2►0.7	SLIGHT DROP
48	SIT DOWN	3.5►1.0	40 ppm MAX. SLIGHT RISE
50	STAND UP	–0.1►0.7	SLIGHT DROP
52	SIT DOWN SLOWLY	2.7►0.9	VERY SLIGHT RISE
54	STAND UP SLOWLY	–0.1►0.7	
58	SIT DOWN HEAD BACK	3.9►0.7	
60	LEFT LEG RAISE	0.0	SLIGHT DROP
	LEFT LEG LOWER	2.3►0.9	SLIGHT RISE
61	STAND UP	–0.3►0.7	VERY SLIGHT RISE
62 – 67	WALKING	0.4►1.1	
68	STATIONARY	0.7	
69*	SQUAT	3.3►0.7	292 ppm HIGHEST RISE
70	STAND UP	–0.4►0.7	DROP TO BASE WITHIN 30 SEC.
71	KNEEL DOWN	3.5►0.9	
72	STAND UP	–0.3►0.7	52 ppm DROP

TABLE 2 (CON'T)

EFFECTS OF MOVEMENT

SUIT 627 – MODIFIED - 2 1/2 INCH FACE RELIEF VALVE FLAP

TIME (MIN) AFTER EXPOSURE	ACTION	INNER SUIT PRESSURE INCHES WATER	Δ ppm HELIUM
74*	SQUAT	3.5►0.7	132 ppm RISE
75	STAND UP	–0.3►0.7	60 ppm DROP TO BASE
76	KNEEL	3.3►1.0	45 ppm DROP
77	STAND UP	–0.3►0.7	
78*	SQUAT	5.1►1.0	152 ppm RISE
79	STAND UP	–0.3►0.7	DROP TO BASE
80	KNEEL	4.2►1.1	DROP 52 ppm
81	STAND UP	–0.3►0.7	
81 +	SERIES OF 10 SQUATS	2.0 AUG DOWN	
	FAST	–0.6 AUG UP	
82	HARD TRISTING AT WAIST 1 MIN.	0.5►1.5	
83	STATIONARY	0.7	
85	FAST SQUAT AND TUCK	6.3►0.7	MAX. 30 ppm SLIGHT
86	FAST SQUAT AND TUCK		
	HOLDING HELMET DOWN	5.7►0.7	MAX. 30 ppm SLIGHT
	STAND UP	–0.3►0.7	

*ONLY SURE RISES ABOVE THE NORM.

N_2O_4 CELL TEST RESULTS OF DEFECTIVE MATERIALS

SAMPLE NO.	VINTAGE	DESCRIPTION	NO_2 DETECTED IN AIR STREAM	VISUAL OBSERVATIONS
9	1971	UNUSED MATERIAL	NON DETECTED IN 4 HRS.	INSIDE UNCHANGED
7	1971 SUIT 606	INVENTORY SUIT WITH NO VISIBLE ANOMALIES.	NON DETECTED IN 2 HRS.	INSIDE UNCHANGED
5	1971 SUIT 606	TUNNEL AND SLIGHT CREASING.	NON DETECTED IN 2 HRS.	INSIDE UNCHANGED
6	1971 SUIT 606	TUNNEL AND PRO-NOUNCED CREASING BUTYL COATED SPOT-REPAIRS.	NO_2 DETECTED 5 MIN AFTER EXPOSURE. ROSE TO 1.7 ppm IN 72 MINS. AND RE-MAINED AT THAT LEVEL FOR THE NEXT 43 MINS.	INSIDE LIGHTER COLOR AT CENTRAL CREASE. OUTSIDE SAME CREASE, NOMEX EXTRUDING THRU SOFT BUTYL COATING.

TABLE 3

N_2O_4 CELL TEST RESULTS OF DEFECTIVE MATERIALS (CONT'D)

SAMPLE NO.	VINTAGE	DESCRIPTION	NO_2 DETECTED IN AIR STREAM	VISUAL OBSERVATIONS
8	1971 SUIT 402	BUTYL REMOVED FROM SMALL AREA OF OUTSIDE SURFACE; NOMEX	NO_2 DETECTED 1.5 MIN AFTER EXPOSURE. ROSE TO 1.2 ppm IN 2 HRS.	INSIDE LIGHTER WHERE BUTYL HAD BEEN REMOVED. EXPOSED NOMEX BROWN AND BRITTLE.
4	1971 SUIT 402	DELAMINATION AND CREASES.	NON DETECTED IN 2 HRS.	INSIDE UNCHANGED
2	1966 SUIT 402	INVENTORY SUIT WITH NO VISIBLE ANOMALIES. 2.5X PHOTOS SHOWED PINEHOLES ON OUT-SIDE TO A SCUFF MARK INSIDE.	NO_2 DETECTED AFTER 13 MINS. EXPOSURE. ROSE TO 0.1 ppm IN 4 MINS. AND REMAINED THERE FOR 103 MINS.	INSIDE UNCHANGED
3	1966 SUIT 526	DELAMINATION AND TUNNEL CREASES.	NO_2 DETECTED AFTER 34 MINS. EXPOSURE. ROSE TO 0.45 ppm IN 13 MINS. REMAINED AT THAT LEVEL FOR 73 MINS.	INSIDE UNCHANGED

TABLE 3

N_2O_4 CELL TEST RESULTS OF DEFECTIVE MATERIALS (CONT'D)

SAMPLE NO.	VINTAGE	DESCRIPTION	NO_2 DETECTED IN AIR STREAM	VISUAL OBSERVATIONS
10	IN USE SINCE 1966 SUIT 838	INSIDE UPPER RIGHT ARM	NONE DETECTED IN 2 HRS	INSIDE UNCHANGED
11	IN USE SINCE 1966 SUIT 888	INSIDE RIGHT ELBOW CREASES AT BEND EXPOSED NOMEX	NO_2 DETECTED AFTER 14 MIN. ROSE TO 9.9 ppm IN 37 MIN REMAINED THERE FOR 69 MIN.	INSIDE LIGHTENED AT CREASES SURFACE NOMEX VISIBLE ON OUTSIDE
14	IN USE SINCE 1966 SUIT 888	INSIDE LEFT ELBOW SLIGHT CREASES AND EXPOSED NOMEX	NO_2 DETECTED AFTER 17 MIN. ROSE TO 3.3 ppm IN 37 MIN. REMAINED THERE FOR 66 MIN.	
12	1971	UNUSED MATERIAL EXPOSED 2 MIN. IN CENTER 1.5 SQ. IN. AREA TO LIQ. N_2O_4	NONE DETECTED IN 2 HRS.	INSIDE UNCHANGED
13	1971	SAME AS ABOVE BUT CENTER FLEXED 50 TIMES IN THE HORI-ZONTAL & VERTICAL DIRECTION BETWEEN LIQUID EXPOSURE & 2 HR. VAPOR EXPOSURE.	NONE DETECTED IN 2 HRS.	INSIDE UNCHANGED

TABLE 3

STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TP-1605		

4. Title and Subtitle	5. Report Date
Nitrogen Dioxide Vapor Penetration of Chlorobutyl Rubber SCAPE Suits Under Operational Conditions	February 1980
	6. Performing Organization Code: TG-FLD-21

7. Author(s)	8. Performing Organization Report No.
Thomas A. Schehl, Thomas W. Beall	

9. Performing Organization Name and Address	10. Work Unit No.
John F. Kennedy Space Center National Aeronautics & Space Administration Kennedy Space Center, FL 32899	11. Contract or Grant No.
	13. Type of Report and Period Covered: Technical Paper
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	14. Sponsoring Agency Code

15. Abstract

Operational Self-Contained Atmospheric Protective Ensembles (SCAPE Suits) and fabric from the suits have been subjected to a series of tests designed to determine the amount of exposure a wearer of the suit would receive if a spill of the hypergolic oxidizer nitrogen tetroxide (N_2O_4) should occur nearby. The results of these tests show that a wearer of a "stock" SCAPE suit equipped with a standard liquid air pack, if exposed to a spill resulting in a 26% increase of oxidizer in the surrounding atmosphere, will experience no detectable concentration of nitrogen dioxide (NO_2) inside the suit for 15 minutes. Thereafter, the NO_2 concentration within the suit will increase for 35 minutes at a rate of 0.07 ppm per minute and then at a gradually decreasing rate until an equilibrium concentration of 3.4 ppm is attained after 100 minutes. Momentary increases of as much as 1.6 ppm can be expected if the wearer were to rise quickly from a squatting position, but the additional NO_2 would be dissipated within three minutes. The effect of liquid and vapor N_2O_4 and of liquid monomethylhydrazine on permeation rates and tensile strength of the SCAPE suit fabric was also investigated.

16. Key Words: Nitrogen Dioxide; Monomethylhydrazine; Chemical Analysis; Protective Clothing

17. Bibliographic Control

18. Distribution: Unclassified - unlimited; STAR Category 25

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	70	$5.25

* For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1980